Journal
of the
British Interplanetary Society

Vol. 9 No. 3 **XXXIV** **May, 1950**

GONE WITH THE EFFLUX

By H. E. Ross

Our Founder, Mr. Cleator, has sketched the history of the B.I.S. from its birth in 1933 down to 1936; it now falls to my lot to cover the period between transfer of Headquarters from Liverpool to London and suspension of the Society's activities at the outbreak of war in 1939. However, I must start by overlapping Mr. Cleator's account, for the switch to London took place gradually during 1936 as the mutual result of dissension and disorganisation in Liverpool and the establishment of a numerically strong and enthusiastic Metropolitan Branch.

Germinator of the London movement was my friend, J. Happian Edwards, whom I had known since about 1925, when we were colleagues at Standard Telephones. I also knew R. A. Smith, who had been closer than a brother to Edwards as far back as schoolday times. Both were, I think, born with the spaceship bug in their veins, so it is not surprising that I, too, became incurably infected with the astronautical virus.

I believe Edwards learned of the existence of the B.I.S. through reading one of Cleator's articles. That must have been early in 1936. Anyway, by June he was not only a member but also Official Representative for the Metropolitan area. His letter proposing the formation of a London Branch and calling for support, appears in the June, 1936, *Journal*. To the same issue he contributed an article dealing with the problems of navigating spaceships. Here we find him advocating the investigation of lunar radio echoes . . . and, incidentally, indulging in a little opportunistic publicity for the products of the 362 Radio Valve Company, of which he was an executive.

As a matter of fact, promiscuous advertising in and out of legitimate text material was in those days a highly organised and exuberantly exploited art. For example, in this same *Journal* we meet an erudite and vitriolic Cleator doing some powerful publicity for Agnosticism under the cloak of an article entitled "Appleton's Inferno and Other Grim Fairy Tales." On another page, under "Notes and News," we find the Editor diligently plugging a well-known lexicon in the following Beachcomber style:—

> "It is now generally admitted by all astronomers of note that a greater problem than was solved would be raised if it were discovered that the famous and mysterious red spot of Jupiter was a gargantuan copy of *Chambers' Twentieth Century Dictionary*. . . ."

How times have changed! . . . Just think, in 1936 it was possible to

INAUGURAL MEETING IN LONDON, OCTOBER 27, 1936.

Back row (left to right): Unknown, C. G. Smith, Allen, *J. G. Strong, Unknown, *R. A. Smith, Unknown, F. Day, *C. Bein, *M. K. Hanson, Unknown.

Front row: Unknown, E. J. Carnell, *A. C. Clarke, *W. H. Gillings, *A. M. Low, Dubois, J. H. Edwards, Miss E. Huggett.

* Present members of the Society.

mention Jupiter's Red Spot without violating the Official Secrets Act or being incarcerated for subversive propaganda.

The inaugural meeting of the London Branch took place on Tuesday, October 27, 1936, at Professor A. M. Low's offices in Waterloo Place.

At this time Professor Low was a Vice-President of the Society, having joined as early as 1934 and thus being one of the first British scientists to appreciate the possibility of astronautics. This is certainly much to his credit, for in those days the subject of interplanetary travel was treated with contempt in technical circles, and anyone who associated himself with it was regarded as of dubious sanity.

The meeting opened with the election of Mr. E. J. Carnell to the Chair. He began the proceedings with a summary of the Society's activities and financial position. Following this he explained the crisis at Liverpool which had developed as the result of overwork and consequent illness of the Hon. Secretary, L. J. Johnson. He further indicated that if the London Branch could be successfully founded it would probably take over administrative duties and become the Headquarters of the B.I.S. This measure, he said, had the approval of Liverpool except for the opposition of Mr. Cleator, who had, however, promised that the Society would still have his every support.

Election of the London Branch officers then took place, Professor Low becoming President, A. C. Clarke Hon Treasurer, J. H. Edwards Director of Research, E. J. Carnell Director of Publicity, and K. W. Chapman and Miss E. Huggett Joint Hon. Secretaries.

Two addresses, one by Professor Low and the other by J. H. Edwards, followed by a general discussion and the taking of a number of group photographs (of which a composite is reproduced here) concluded the lengthy proceedings of this meeting. We have come a long way since that night and it is interesting to note that there was talk (not for the first or last time) of changing the Society's name to one "less imaginative." Fortunately, one can reflect with no little satisfaction that an acceptable alternative might now well be even more "visionary."

During this time I was being drawn into the whirlpool as the result of several enlightening and intriguing conversations with Edwards. In short, I began to ponder space travel instead of laughing at it. However, I did not actually join the Society until December of that year—an almost unprecedented resistance to volatile persuasion, as anyone who has known Edwards will agree.

The meeting at which I finally made up my mind to do something about interplanetary flight was, I think, the informal gathering of Tuesday, November 10, 1936. It was held for the purpose of ascertaining the views, interests, capabilities and intentions of the London Branch. The rendezvous on this and several subsequent occasions was "The Mason's Arms," Maddox Street, not far from Piccadilly. Pre-war members of the B.I.S. have met in many strange places—some of them palatial, some of them markedly otherwise, most of them pubs—but the London Originals will, I think, always retain a nostalgic affection for "The Space-Shippers' Arms," as we came to call it.

Alas, time and much efflux has dimmed memories of that evening. About all I remember is a sea of about 30 fantastically assorted faces, an incredible

aroma of fish, beer and tobacco, a glass-fronted wall-case of toy soldiers—and a heck of a noise. . . .

Still, some business must have been done. Anyway, I see that the February, 1937, *Journal* records the intention of overhauling the Society's Constitution. However, as the meeting was an informal one, no committee could be formed and decision on the matter was put off until the following Sunday, the 15th, when a deputation from Liverpool, including the Hon. Secretary, Mr. Johnson, was due to attend.

At this second meeting, also held at "The Mason's Arms," agreement was reached and a Constitution Committee elected, the members chosen being E. J. Carnell, K. W. Chapman, A. C. Clarke, J. H. Edwards, W. H. Gillings, Miss E. Huggett, and R. A. Smith.

The work of this body came to fruition when the new Constitution was formally adopted at the Annual General Meeting of February 7, 1937. This, too, was held at "The Mason's Arms." After that the Council of the Society stood as follows:—*President*: Professor A. M. Low; *Vice-Presidents*: P. E. Cleator and L. J. Johnson; *Hon. General Secretary*: Miss E. Huggett; *Treasurer*: A. C. Clarke; *Organising Secretary*: R. A. Smith; *Publicity Director*: E. J. Carnell; *Research Director*: J. H. Edwards; *Members' Representative*: H. Bramhill. Under this régime the Headquarters of the Society became established at R. A. Smith's address, 92, Larkswood Road, South Chingford, London.

During the course of that year a tremendous amount of work was done in several spheres of activity. Somehow or other Carnell, working in his spare time, managed to produce monthly single-sheet *Bulletins* in addition to a couple of excellent *Journals*. Regular meetings were arranged and two competitions organised. The first of these was for the design of a Spaceship Launching Equipment. This was won by D. H. M. Jack, of Marlborough, Wilts. Prize in the other competition, for jet-propelled model airplanes, was to have been a cup generously offered by Professor Low. Unfortunately, this contest never took place for the very simple reason that response from the membership was nil.

As a matter of fact, one of the greatest difficulties under which the officers of the Society laboured was the impossibility of finding out what *did* interest the bulk of the membership. In addition to a Members' Representative a Non-Technical Committee was formed especially to probe the mystery, but so far as I know the answer was never found. True, we did occasionally get suggestions and criticism, but for the most part the Council had to settle the activities of the Society with little exterior guidance.

Undoubtedly the most successful function of the year was the debate of October 5 on the motion "That the Venue of this Society be Moved from the Moon to New York." We could, of course, always count upon a good attendance whenever Professor Low put in an appearance, but in this case the foundation-shaking nature of the "proposal," even though not seriously intended, contributed to a lively evening. As a matter of fact, it was a "put up job"—so much so that we had extreme difficulty in persuading anyone to second the motion. However, since our Research Director had elected to oppose the motion, there was really no choice in the matter. It had to be R. A. Smith, for he was the only person capable of arguing Edwards to a standstill. This he did

indeed do with such effect, that, although according to the official report Edwards "technically annihilated the New York trip," yet Smith actually carried the vote by 16 to 13! . . . Incidentally, he has never forgiven himself for this victory.

The Technical Committee, of which I early became a member, was formed in the autumn of 1936, but it did not acquire an official status until after the passing of the New Constitution. The committee, effectively headed by J. H. Edwards in his capacity of Research Director, was largely responsible for the policy of the Society. It stood for a scientific consideration and exposition of the subject of astronautics and its members devoted themselves wholeheartedly to the task of rationalising and contributing to contemporary theory.

Many aspects were dealt with, but the principal work of the Technical Committee, undertaken with the object of testing the feasibility of a lunar voyage in the light of current knowledge and techniques, focused upon an attempt to design a spaceship capable of the round trip. The B.I.S. has been criticised for doing this instead of experimenting with rockets, as several other societies of that period did. But two things must be remembered—firstly, that the income of the Society barely covered running expenses, so that no funds were available to establish a rocket research station such as would satisfy the regulations enforced by law; secondly, it seemed eminently logical that, being an interplanetary society, we should prove to ourselves that a reasonable extrapolation of science would in fact render the crossing of space practicable. . . . For, it should be recalled, up to that time the launch weight of a spaceship was commonly assessed as likely to run to hundreds of thousands of tons. As against this, the "B.I.S. Cellular-Step Spaceship," based upon a postulated exhaust velocity of 3·7 km./sec., weighed only 1,000 metric tonnes.

The measure of success attained as the result of an extremely lengthy and detailed study of the problems and possibilities can be judged when I say that the vessel ultimately designed is, at the time of writing, still the only published conception which offers at least rudimentary solutions to every requirement. Of course, for many obvious reasons it is not a practical proposition—far from it. Nevertheless, on one score alone it was worth while—it taught the members of the Technical Committee the subject of astronautics. . . . It even taught our Director of Research a good deal, despite the fact that he started with a truly encyclopædic knowledge of the theory.

The Technical Committee met regularly for general discussion and co-ordination at least once a month in Mr. (now Dr.) A. Janser's comfortably appointed rooms in Great Ormond Street, but a tremendous amount of work was done outside these sessions.

The rendezvous at Janser's apartments, being conveniently situated near the centre of London, was also used for the reception and entertainment of distinguished visitors. One such was Dr. Otto Steinitz, well-known German engineer, astronaut, and, among other things, Chairman of the *Fortschrittliche Verkehrstechnik, E.V.* Dr. Steinitz was then passing through England on his way to America, and we had the pleasure and honour of his presence at the November, 1937, meeting of the Society. On this occasion he gave us a short address conveying greetings from German astronauts and expressing hope for

closer collaboration between the interplanetary societies of England, Germany and America. . . . Alas, the reckless Nazi régime—of which Dr. Steinitz himself was then a victim, despite outstanding engineering services to his country during the 1914–18 war—intervened to sever all communication with the continental mainspring of astronautics. . . . Indeed, at one time soon after we had some grounds for believing that the B.I.S. was being dogged by agents of the Gestapo.

Mr. Cleator has related that, in 1934, he was approached by H. Grindell-Matthews in connection with the latter's idea for using a massed rocket barrage for defence against hostile bombers. . . . Time, we are told, marches on. Evidently it also sometimes marks time, for the summer of 1937 saw members of the Technical Committee closeted with Matthews on precisely the same subject. The Tor Cloud mountain-top rocket research station described by Cleator was still there and Grindell-Matthews was still keen to start experiments. The only thing missing was the backing of the War Office. Needless to say, he did not get it.

Yet Grindell-Matthews's ideas must have been worth something. Else how did he come to be carrying a photostat copy of a Government cheque for £25,000, paid to him for inventions in the Great War? And, of course, London *was* ultimately defended by a massed rocket barrage. . . . Verily, a prophet in his own country. . . .

But there was really something else missing—people to do the experiments, for Matthews was no rocketeer. Truth to tell, neither was any member of the Technical Committee—at least we had no practical experience. However, collectively we did know a good deal about rockets—and we were his last resource. For Grindell-Matthews, at considerable personal risk, had travelled Germany contacting rocket engineers. Apparently he had even visited a factory making war-rockets, and had been present at military field trials! More, he had laid on a private airplane in readiness to pick up a well-known engineer, who shall be nameless. . . . Then something happened: the Third Reich reacted and the engineer disappeared. If I remember G.-M. correctly, one of our own Government agents who happened to be taking an interest in German rocketry, also vanished round about the same time.

All this was very amusing, but did not get the B.I.S. anywhere. We made tentative suggestions and Edwards and Janser (the latter in his professional capacity of research chemist) produced an estimate for the funds needed to establish a laboratory and start experiments. But nothing came of it. The B.I.S. was not destined to become the British VfR.

Incidentally, Janser and Edwards between them studied something like 120 different fuel combinations, covering liquids, solids, metalloids, colloids, and plastics. Some interesting notes, conclusions and suggestions are contained in two articles by Janser, "A Contribution to the Fuel Problem" and "Fuels and Motors," which appear in the December, 1937, and January, 1939, *Journals* respectively.

Throughout 1938 there was a stepping up and extension of activities. No *Journal* appeared during that year, however. This was partly due to lack of revenue, partly to the fact that we were waiting for finalisation of the spaceship designs, and partly because we were building an Experimental Research Fund.

H. E. Ross (the author), J. H. Edwards, H. E. Turner, R. C. Truax, R. A. Smith, M. K. Hanson and A. C. Clarke—at a meeting on July 17, 1938, at Smith's Chingford home. The occasion was a welcome to Midshipman (now Lieutenant-Commander) Truax, then visiting this country on a U.S.N. training cruise. He is seen holding one of his small experimental liquid-fuel rocket motors.

Absence of *Journals* was to a certain extent compensated by monthly and, after August, more voluminous *Bulletins*. This change followed installation of the Clarke-Temple-Hanson complex in a lofty eyrie at 88, Gray's Inn Road, W.C.1. Here, armed with one or two battered typewriters, a fifth-column duplicator, much mutual advice, and an irrepressible desire to write, they took over the editorial and publicity duties thankfully relinquished by Carnell. In next to no time the trio had programmed enough schemes to keep them busy for a lifetime. . . . The *Bulletin* was to "contain not only full reports of all meetings, but also many other matters of current interest which would not be suitable for the *Journal*." . . . It was to be "designed particularly to interest the provincial members, who it is felt have been somewhat neglected in the past." . . . It was hoped "to include biographical sketches, members' correspondence, library and affiliated society reports and anything else that seems of interest and topicality." Moreover, it was probably to contain "a large number of equations and graphs" . . . which "may be printed as a separate supplement to the *Bulletin* so that they can be filed by the technical members and safely lost by the non-technical."

Believe it or not, we did get nearly all that—including no less than *three* graphs. . . . One more than was really necessary to sustain the plural. . . . However, the only equation I can find is that in which Arthur Clarke proves that an egg-timer could be used to measure velocity. . . .

I have mentioned the Research Fund. This was created with the dual object of providing a new field of activity for the membership and in order to permit an Experimental Committee to test one or two novelties arising out of

our attempt to design a spaceship. Contributions were pegged at 5s. per head and were conscripted voluntarily at the point of the hat or pen. To this brigandage we had a fair response and even one gift of £10 from a lady member.

The Experimental Committee, which met monthly, really consisted of the Technical Committee with their thoughts reoriented—so it is not surprising to find Edwards thinking of the Coelostat and Smith designing and making it. I have a suspicion that one of the principle reasons for constructing this piece of apparatus was to prove to Edwards that it wouldn't work. Actually, however, it did. . . . In fact, we demonstrated the Coelostat in action, furnishing a stationary image of a revolving disc, at the Science Museum, South Kensington, on March 7, 1939.

Next item on the programme was an altimeter. This started off as an alarm clock. No altimeter materialised: instead we discovered the secret of the Swiss clock industry—Horogenesis. Evidently all you have to do is to make one clock and then keep taking it to pieces, thus breeding more clocks. In the end we had five clocks, parts of which have been following me about ever since. . . .

After that we started all over again; this time using a spring-weight combination and an aluminium disc flywheel. However, this too gave a lot of trouble and the sands of peace ran out before it could be completed. The same thing happened with our ideas for a light-weight electric battery and rocket proving stand.

The history of all this is recorded in the *Bulletins* and subsequent *Journals* of that era. If you favour humour I can especially recommend the *Bulletins*, which Clarke and Temple deliberately pixilated in response to an appeal for more "popular" material. This left the *Journals* for serious technical expositions.

Being rather pixilated, too, as the reader may have noticed, I would like to reproduce some notable *Bulletin* articles here, but space forbids. Perhaps if enough members pester our Publications Committee you may be regaled with reprints of items like "Chingford Chiaroscuro" (a layman's first experimental meeting) and "An Outsider at a Technical Meeting," both by W. F. Temple, or A. C. Clarke's "The Interplanetary Approach," in which he describes the kid-glove, the rapier, and bludgeon techniques of broaching the subject of interplanetary travel to one's acquaintances.

Neither is there sufficient space to tell various anecdotes such as the one involving Arthur Clarke, who, whilst laden with a parcel of *Journals*, at the time of the I.R.A. outrages, was suspected of harbouring a time-bomb. Nor can I tell the full story of how, round about the same time, we nearly lost our Research Director to the Law simply because he happened to be casually swinging a large empty suitcase whilst innocently inspecting a jeweller's window.

Immediately news of the B.I.S. spaceship design became bruited about, during the second half of 1938, the Society got all the publicity it could handle—and a lot it never had the chance to correct. Newspaper reports and magazine articles appeared everywhere as if by magic. We even stole half the photo-page of a national Sunday newspaper from Hitler during the week-end of the Czechoslovakian crisis. And in February, 1939, Mr. Buckley Hargreaves, the

B.B.C. film critic, gave an account of B.I.S. activities over the air from the Northern Regional station. Following this (I quote from the *Journal*), "we answered criticism from intelligent readers of *The Listener* for thirteen consecutive weeks in the correspondence columns, and finished triumphantly with our critics tamed or converted."

Yes, of course there was criticism. . . . What else could one expect when reporters made statements like—"The compartment (pressure cabin) is so light that the occupants would probably only break their legs on landing."

It now simply remains for me to say that outbreak of war terminated all activities of the Society. This decision was promulgated following an Extra-ordinary General Meeting of the Society. However, a nucleus of the Society's officers managed to keep in touch during the whole period of hostilities and a good deal of work was in fact done privately by several of them.

This, then, is the history of the pre-war B.I.S. after transfer of Headquarters from Liverpool to London. Or rather it is one facet of the whole story, which really could only be dealt with as a symposium of personal reminiscences—for some of the inner history has been lost through fire.

If the preceding account has been frivolous that is not altogether the fault of the writer, since the pre-war B.I.S. *was* pixilated. . . . And why not? We were unorthodox. Nobody could have been more unorthodox than, for instance, our Research Director. But space will not be crossed by being orthodox, and ideas must come first. The V.2 was unorthodox before it was invented. . . . More, it was almost a technical impossibility. . . .

I am not defending the impracticability of the B.I.S. spaceship, but I am defending the attitude which promoted its evolution. The spaceship of ultimate fact will be attained through a series of successive approximations, of which the B.I.S. ship was an early drawing-board specimen. It served its purpose in that only by attempting to resolve theory into a practical conception is it possible to determine the feasibility of an engineering proposition. And it is better to do this before an expensive experimental programme has begun. One should always make sure that the ladder is long enough before beginning to climb. That, indeed, is why so much is known about the parameters of, for example, the German A.9/A.10 project, which reached the drawing-board stage, but which for various very good reasons is still not practicable.

The Earth is breath-takingly lovely, and it is difficult to imagine a more enchanting elysium for the human race. Yet because of man's consuming desire to see, to know, and to understand, he finds himself impelled to cross space. Some people will never experience this urge or be able to appreciate the Promethean compulsion of ideas. But interplanetary enthusiasts do. All this and the heavens too, is their philosophy. It reflects a belief that man's destiny rests in his own hands and that his deeds should honour the intellect with which Nature has endowed him.

Beside such a conception the history of the B.I.S. is but a little thing. All one really need know is that the British Interplanetary Society, like the Universe, was once started.

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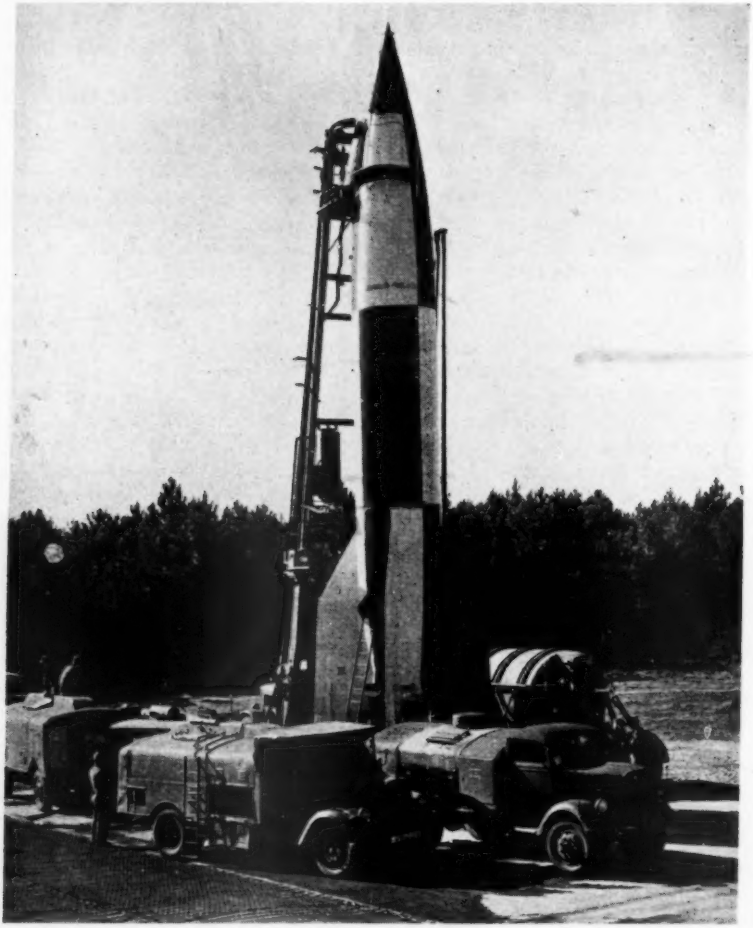

V2 Launching Preparations.

A V2 rocket being prepared for launching; alongside the rocket is a temporarily erected structure, with platforms at various heights, to facilitate pre-firing checks of equipment, fuelling, etc. Around its base are the road tankers, bringing the propellants: liquid oxygen, alcohol, and hydrogen peroxide (for the pump-turbine).

FILM SHOW

REVIEWED BY W. N. NEAT

(A report of the meeting of the Society held at the Science Museum Lecture Theatre on December 3, 1949.)*

If the number present were the only criterion, film shows organised by the Society would be among our most successful functions, and that held on December 3 proved to be no exception. Before a capacity house in the Science Museum Theatre, the programme began with some coloured reproductions of a number of Chesley Bonestell's graphic paintings of surface conditions on other planets, most of the pictures shown being taken from the Bonestell–Ley book, *The Conquest of Space.*

Bonestell's work must be examined closely and at length to be fully appreciated—his use of colour, his execution of light and shade and his photographic plausibility must make him unique among illustrators of astronautical subjects, if not among illustrators of scientific subjects in general.

Following these pictures, two short films of French origin were shown. The first of these depicted mainly the elaborate preparations which were carried out in order to obtain records of two solar eclipses, and some of the results obtained therefrom. Retarded sequences taken of the actual eclipses were shown, the corona effect during the moment of complete coincidence being especially interesting. To one interested in astronomy in only a detached sort of way, this film was particularly intriguing, because it portrayed in a matter of a few minutes, that which astronomers might wait a lifetime to see and then probably miss because of the weather!

The second of these two films consisted of a series of photographs of solar protuberances. Of chief interest was the scale of these emanations and the fantastic velocities involved. Most of this film had been speeded-up, so that the characteristic movement of the "flames" could be easily appreciated.

Then followed the main feature of the programme—the Crown Film Unit's "The German A4 Rocket." This film, which was produced during the British programme of V2 firings at Kiel in 1945, documents the final handling procedure, the fuelling and firing sequences carried out for one of these missiles. It is admirably produced, and the commentary is, at the same time, both lucid and entertaining. I appreciated, too, a fine touch of the dramatic in the impressive opening shots of V2's being launched, complete with full sound effects. No brazen gong or lion's roar could have improved upon this introductory motif.

As far as I was concerned, one of the most thought-provoking aspects of this film was a realisation of the immense amount of preparation necessary to induce one of these 12-ton rockets into the air. I let my mind dwell on the various complicated movements required, the last minute adjustments, the elaborate fuelling procedure and the hundred and one things which had to be remembered and carried out, each at its proper time. Then I used a little imagination and projected my thoughts to the interplanetary problem,

* *Since repeated on May 6, 1950.*

to a much larger and considerably more intricate rocket, with infinitely greater things at stake, and I soon appreciated what a complicated and critical business the launching of the first extra-terrestrial rocket will be.

For most people at this show, "Operation Backfire" was somewhat marred by the inclusion of a rather incongruous second reel. This, by mistake, had been taken from an early German film on the development of aircraft rockets. But, once one had realised what had happened, and that a V2 motor was *not* being fitted under the wing of a Heinkel III, one could appreciate this interloper for its own sake. Adopting the philosophy that there is no such thing as an ill wind, I was particularly interested in what was claimed to be the first flight of an aircraft (a Heinkel 112) propelled solely by a rocket motor, and somewhat grimly amused by a spectacular crash, during a very early rocket assisted take-off by a Heinkel 116. After "Operation Backfire" came another Crown Film Unit production, namely "Faster than Sound." Obviously not intended for a technical audience, this film presented a brief account of the work which preceded the first launch of the Vickers Transonic Model. As most readers will remember, this was a test vehicle, rocket propelled and launched from a Mosquito aircraft over the sea, in order to investigate aerodynamic phenomena in the sonic range. Knowing a little of the considerable problems which this project involved, I felt this film erred, if anything on the score of brevity. I particularly thought the people who designed and developed the rocket motor received rather rough justice. Only one episode of their work was included and that showed an early attempt with a motor which failed to work!

However, remembering that this film was intended for general release and that to criticise it from a purely technical aspect is being rather unfair to its sponsors, I would say that it presented an interesting account of an interesting project. I particularly liked the concluding action shots of the test vehicle falling away from the parent aircraft and streaking ahead as the rocket motor took over.

The session was concluded, most appropriately, on a more futuristic note. This consisted of the fifth and final part of the Gaumont-British film on atomic physics. This is the section of the film which deals with atomic physics as it is applied to the atomic bomb and power generation from nuclear reactors. It contains some highly instructive animated diagrams illustrating the principles of nuclear fission, the chain reaction, the atomic pile and the inevitable bomb. Also described are some of the Wellsian apparata which we have now come to associate with atomic physics, while some of the more important discoveries which have led to the present state of the science are described and illustrated.

While I do not think either rockets or interplanetary travel are once mentioned in this film, I am sure that none but the most unimaginative of us would question its inclusion in a programme dealing mainly with those and kindred subjects. The implication is obvious; from work which has already been done, it appears certain that the realisation of interplanetary travel will not be achieved without the application of atomic power to provide the motive force. Let us but hope that the destructive power of the latter, ill used, will not disastrously postpone the fulfillment of one of mankind's most ambitious projects.

THE EFFECTS OF INTERPLANETARY FLIGHT

(A Report of the Discussion at the Meeting of the Society held in London, on February 4, 1950)

By W. H. Gillings

The suggestion that extra-terrestrial colonisation might eventually prove the only solution to the problem of supporting Earth's increasing population was advanced in the course of an animated discussion on "The Effects of Interplanetary Flight," at the February meeting, when members indulged in airy speculation on the possibilities that would be opened up by the achievement of the Society's aims.

In introducing the topic, our Chairman, A. V. Cleaver, broached the question of whether, in the fairly distant future, the colonisation of other planets would relieve the pressure of population which by that time might have caused the Earth to become very overcrowded. He pointed out that, according to Julian Huxley's estimate, to-day's world population was 2,200,000,000, and if it continued to multiply at its present staggering rate, it would, by 2,300 A.D., have reached the formidable figure of 100,000,000,000.* At the same time, he hinted at some of the effects which spaceflight might have on other branches of science, and invited members to consider its influence on our philosophical and social outlook, especially if it were to result in the discovery of intelligent life elsewhere in the Solar System.

Opening the discussion, A. C. Clarke said that if, when we reached the planets, their environments proved so hostile that we could only establish scientific bases on them, the number of human beings who would venture outside the Earth would never be more than a few thousands; and although spaceflight might well revolutionise our knowledge in other fields, after the initial excitement had worn off it might prove an anti-climax. If one took a more optimistic view, he supposed that quite large and eventually self-supporting colonies would be established on the Moon and on Mars; but how quickly these groups would become politically important he could not foresee, since a single scientific discovery might transform the situation at any time. For example, if it was found that one could live longer under low gravity, all the over-70's might emigrate *en masse* to our satellite.

While drawing a parallel between the rise of the United States as a world power and the emergence of extra-terrestrial colonies, he emphasised that fundamental differences in development were involved. We had to face the fact that there was no other world in the Solar System on which men might live without mechanical assistance, and if unrestricted colonisation was to be carried out, concessions would have to be made either by us or the planets concerned. He thought it would be easier to change the planets than the human species, and with the powers we should possess in another few centuries we could effect very radical alterations to the atmospheres, temperatures and even the orbits of the planets, as suggested by Professor Zwicky. He assumed that we would not encounter intelligent life in our explorations; otherwise there would be no question of exporting our peculiar ideas of what constituted an equable

* *Some authorities do not accept this figure—Ed.*

climate. But any other really intelligent race in our own Solar System would presumably have reached our world long ago.

Taking up the Chairman's theme of Earth's population problems, the Secretary, L. J. Carter, emphasised that two-thirds of the world's present inhabitants lived at starvation level and that we could expect a close race between further population growth and advancing science in the near future. Interplanetary flight, he thought, alone could provide a permanent solution to the problem. Not only might it provide new raw materials which would prove of economic advantage to us, but Mars or Venus might become the future granaries of Earth. We could certainly anticipate the establishment of small planetary colonies, of artificial satellites and even planets, which might avert catastrophe for the human race two or three centuries hence.

Replying to criticisms of this view, Mr. Carter insisted that although the world must obviously rely on the agriculturists for an immediate remedy, "we are the last line of defence, and if we fail, Nature will provide the usual answer by wiping out those millions for whom there is not enough to eat."

Among those who disagreed, A. E. Dixon thought that improved growing methods would enable us to produce adequate food long before we were in a position to colonise other planets, while H. E. Ross found it difficult to visualise the possibility of transporting 55,000 people per day across space in order to stabilise Earth's population at its present figure. Mr. Dixon was more inclined to utilise the spaceship as the only safe means of "letting atomic energy rip": once we had learned to control it out there, we could bring it back to Earth and apply it to down-to-earth problems.

Mentioning the revised speculations concerning Jupiter and Venus, Mr. Carter also cautioned those who pointed to the inhospitable conditions of other worlds not to take astronomers' statements too seriously; they were often based on flimsy and indirect evidence. The question of whether or not the Moon had a tenuous atmosphere had still to be settled, while the "canals" of Mars still found their adherents.

K. W. Gatland introduced a more philosophical note. He pointed out that the possibility of interplanetary flight had lived in men's minds for centuries, and that now it had become a technical proposition the question "Why?" had supplanted the question of "How?" The motives of astronautics were likely to be challenged as long as the majority of individuals were educated only to a level of commercial subsistence and were content with an attitude of mind which did not look beyond its immediate confines. The mass concept of the universe to-day was no more advanced than it was at the time of Copernicus, and the cardinal benefit of spaceflight might prove to be the extension of the stream of human consciousness which would result. This prospect, to him, transcended all other benefits in terms of scientific progress, however desirable.

In a typically humorous but well-reasoned argument, R. A. Smith contended that there must be some deep consciousness in all B.I.S. members that interplanetary travel was an essential phase in the development of the mass intellect, which would bring an increase in man's appreciation of the universe. He thought it important that man should not approach this phase by sending explosive ambassadors to the Moon; otherwise, it might lead to a high-powered

bomb Cup Final, the winner to carry off what was left of the satellite. He liked to think there would be some properties of the Moon left for his descendants to enjoy; having examined the Ley-Bonestell volume with a mixture of delight and horror, he would prefer to consider the problem of colonising the Moon rather than any of the planets.

He emphasised that the cost of sending out a lunar expedition would be so appalling that it would only be sent if it could be thoroughly well organised with a specific object in view, with the result that they would get a community set up based on the soundest principles, with every member imbued with a sense of responsibility and performing an essential function. It would be disciplined by reason, founded for a purpose, with a common end in view. It would be a long time before it became a large aggregation of human beings; but on the other planets man would have the chance to develop as a sensible, intelligent being. As their first objective, therefore, the Moon was important to all of them, and their first principle should be to ensure that no government of this world had any right to regard it as a conquerable piece of territory.

Enlarging on the theme of man's extra-terrestrial development, H. E. Ross urged that we should look forward to increasing our understanding of the universe and to acquiring a philosophy that would enable us to bear our new responsibilities. The first extra-terrestrial communities, he pointed out, would be technocracies, which would have a chance at last; they might furnish a truly Utopian example to the Mother Planet. In fact, interplanetary travel provided the first opportunity for man to change in respect to his environment, and this might well prove to be part of the grand scheme of the universe towards the evolution of really intelligent life.

G. V. E. Thompson wanted to see the Society paying more attention to the incidental technical problems associated with the initial attempt at spaceflight. He thought its actual achievement would tend to speed up life on Earth still further, but when the Moon was reached it might be decided that interplanetary travel involved too great an effort, and we would have to make great propaganda to overcome any such opposition.

A more cheerful outlook was introduced by Miss Helen Winnick, after Mr. Clarke and Mr. Ross had scotched the idea of a new member that we might have crossed space already—as Martians in search of a more congenial home. She hazarded that the most likely results of the achievements of spaceflight would be Jane Russell in "The Girl from Mars," the papers full of Martian cookery hints, and a rush by dress designers to the science fiction magazines to copy the interplanetary costumes—on wearing which the women of the world would probably die of pneumonia and our population problems would vanish!

Summing up after many other members had expressed their views, the Chairman said it seemed to be agreed that space-travel would not cause a revolution in human thought overnight, but that over a century or more the average man would grasp its implications through the medium of books, films, and so on. He thought the emphasis on the state of food production which had been evident in the discussion was perhaps merely a reflection of the state of the nation to-day! However, there were few phases of human activity which would not eventually be affected by astronautics, as the discussion had amply demonstrated.

THE TESTING OF ROCKET MOTORS

By Dipl. Ing. H. F. Zumpe

(*A paper read to the British Interplanetary Society, in London, on March* 4, 1950)

Introduction

The purpose of this lecture is not to explain principles and construction of instruments used for measurements in rocket motor development, because these instruments are common to the whole field of science and not particular to rocket motor investigations as such. The object is to show the connection between the two main problems arising from rocket motor development and the methods of measurement necessary to solve these problems, addressing more the reader who is not particularly familiar with the subject. Both problems are interconnected and can be expressed by the two questions:—

1. What can we do to obtain a specific propellant consumption as small as possible?
2. How can we control the very high heat loads on the combustion chamber?

First of all we have to get a clear view of the present position. The very few existing rocket motors are products of a development carried out under severe time limitations; the gain in scientific knowledge obtained from these developments has not been very great. Any construction of a new rocket motor, even if only the scale has to be altered, means more or less a new development. With the exception of some practical knowledge such as the magnitude of the specific impulse to be expected, some figures about the coolant velocity required, some means of avoiding hard starts, etc., there is no general information which we can derive from past developments. There is still a wide field for the imagination of the designer, which is always a sign of missing knowledge of the rules which we are seeking.

The pioneer work for the rocket motor has still to be done, similar to work which Ricardo did for the internal combustion engine, Stodola for steam turbines and Prandtl and his school for aerodynamics.

A question of great importance is how far we can apply existing thermodynamic and heat transfer theories. As long as this question remains to be answered it seems better to concentrate on collecting facts for different test conditions and to wait until some obvious correlation between the test parameters shows itself and suggests, more or less automatically, a line of approach in forming a correct picture of what goes on. This picture has then to be proved or revised by putting more accurate questions to nature until it is possible to form the appropriate theory.

It is clear, of course, that research on rocket motors will not alter the present picture of physics. The basic ideas of gas kinetics for example will still stand for application to the rocket motor, and there is no doubt that they can be used at once for forming a preliminary picture. But it is at least doubtful whether it is correct to apply certain special equations derived from the basic laws of gas kinetics, e.g. the expansion formula. It should be kept in mind that these derived laws are valid only for quasi-stationary conditions which apply to all

heat engines hitherto known. But what is the position for the rocket motor in which the average molecule goes through a very wide range of states in a time of about 10^{-3} sec. or less after the reaction?

The second large problem, heat transfer, is in a similar state. Consider, for instance, heat transfer between combustion gas and inner wall. There are convenient formulae available for calculating the amount of heat transmitted from gas to wall, but they are derived, and therefore valid only for a certain temperature range and low flow velocity, and not in any case for supersonic velocity. It would be useless to start an investigation for obtaining new values of certain factors which are used in those formulae. The present equation only expresses the picture which has been adopted under previous conditions, while our new problem involving, for example, supersonic gas flow, must lead to a quite different view and therefore to a different formula. The new factor in the old formula can never be a constant, as it should be, and is true only for the conditions of the special test for which it has been derived.

It follows that our method of questioning nature, or in other words, our method of measurement, has to be lined up with a change in attitude. Asking for gas temperature in the combustion chamber, for example, has not much sense, if it should prove that the thing which our thermometer shows us as temperature does not represent the equivalent to the kinetic energy or gain from the chemical energy spent—the real feature for which we are asking.

The subject has been divided into two main parts, the first dealing with thermodynamic processes in combustion chamber and venturi, the second with problems of heat transfer and cooling. After a review of the few well established observations and facts which are beyond any doubt in their application to our problems, appropriate methods of measurement are described.

The vast field of auxiliary equipment necessary for running rocket motors such as propellant feed systems, control devices, etc., is not covered here as the problems of development and methods of measurement are very similar to those encountered in general engineering tasks and therefore not peculiar to rocket development.

I

Thermodynamic Investigations

The rocket motor belongs to the class of internal combustion engines and exists for the purpose of transforming chemical energy into mechanical energy in the special form of impulse mc, where m represents the mass of combustion gas generated per second and c the velocity of the gas parallel to the direction of movement of the vehicle which is driven by the rocket motor. As in the development of any internal combustion engine the knowledge of the ratio: gain of mechanical energy to expenditure of chemical energy is of paramount importance, this ratio being called the efficiency. It is sometimes useful to consider energy per second, that is, the power.

For obtaining the energy expenditure it is sufficient to measure the weight of propellants burnt during one second. The free energy developed during the reaction of one weight unit of the propellant mixture can be measured by tests in the bomb calorimeter; it is already well known for most cases. Concerning

the second factor in the above-mentioned ratio, the matter is not quite so straightforward, because on the test stand the motor does not produce power. Therefore we have to consider the power developed in the gas flow, which, in cases where the velocity of the rocket vehicle equals the gas velocity, is transmitted completely to the vehicle. We have, therefore:

$$P = \frac{w}{g} c^2 \times \tfrac{1}{2}$$

where w = weight of the gas used per sec.;
g = gravity constant;
c = gas velocity;
P = power developed.

The power available from the reaction process can be expressed as:

$$P_{th} = \frac{w}{g} c_{th}^2 \times \tfrac{1}{2}$$

where c_{th} is a theoretical limit for the gas velocity if the total chemical energy could be transformed into kinetic energy.

The efficiency is then:

$$\eta_E = \frac{P}{P_{th}} = \frac{c^2}{c_{th}^2}$$

The value of c_{th} is easily derived from the known chemical energy constant of the mixture. We consider the kinetic energy of one molecule after the reaction assuming the whole of the chemical energy being transformed:

$$e = \tfrac{1}{2}\mu c_{th}^2$$

μ being the mass of one molecule.

Let n be the number of molecules in 1 kg. of gas, E_{ch} the chemical energy before reaction in 1 kg. of gas in calories and J the Joule constant for the transformation of calories into mkg., then we have:

$$\frac{E_{ch}}{J} = ne \text{ mkg./kg.}$$

$$\therefore \quad \frac{E_{ch}}{J} = n \frac{\mu}{2} c_{th}^2$$

The product $n \times \mu$ is, however, the mass of 1 kg. of gas, which equals $\frac{1}{g}$; we have therefore:

$$c_{th} = \sqrt{\frac{2g}{J} E_{ch}}$$

To determine the efficiency we have still to measure c; this is not possible, but we can obtain it by measuring the thrust F, using the equation:

$$c = \frac{Fg}{w}$$

The efficiency is now:

$$\eta_E = \left(\frac{F}{w}\right)^2 \frac{g}{2} \frac{J}{E_{ch}}$$

This represents the so-called "inner efficiency" of the motor and should not be confused with the "outer efficiency," which is often used in rocket ballistics and indicates the ratio of the energy transmitted to the vehicle to the kinetic energy developed in the jet. This latter is dependent on flight conditions, whereas η_E refers only to the process within the motor itself.

The value η_E is quite useful in comparing two different rocket motors using the same propellants, but it does not give a true comparison between different motors using different propellants. Our aim in rocket development is to obtain the highest possible power output for a minimum expenditure of propellant. A motor of low efficiency using high energy propellants can give a better performance than a motor of high efficiency using propellants of low energy content.

To obtain a suitable value for general comparison, it can be shown that the product thrust × burning time is proportional to the amount of work done. Using the power equation

$$P = Fc \times \tfrac{1}{2}$$

and knowing that work done is only another expression for energy, we get

$$E = Pt = Fct \times \tfrac{1}{2}$$

where t is the burning time.

Using again

$$F = \frac{w}{g} c$$

we obtain

$$E = \frac{w}{g} c^2 t \times \tfrac{1}{2}$$

$wt = W$ means the total propellant expenditure during the burning time. It follows, therefore, that

$$E = \frac{W}{g} \frac{c^2}{2} = \frac{Fct}{2}$$

which represents the work done during burning time.

The ratio $\frac{Ft}{W}$, or $\frac{F}{w} = I_s$ which is the same, is therefore a measure of the work done by unit weight of propellant gas. This is called specific impulse and can be obtained by simple thrust and consumption measurements.

Present practical I_s values range from about 190–220. The gas velocity can be derived from the equation

$$c = g I_s$$

Using the theoretical gas velocity c_{th} obtained from the chemical energy content of propellants we obtain

$$I_{s_{th}} = \frac{c_{th}}{g}$$

which allows us to introduce a new expression for "efficiency"

$$\eta_s = \frac{I_s}{I_{s_{th}}} = \frac{c}{c_{th}}$$

This impulse efficiency is connected to the energy efficiency η_E by the simple relation

$$\eta_s = \sqrt{\eta_E}$$

In comparing efficiencies it is, therefore, important to refer always to the same kind of efficiency.

Efficiency and specific impulse can only give information about the general performance of the motor as a whole. It is, however, the task of the scientist to improve the object of his investigations; the methods of measurement must tell him which part or which process he must alter in order to obtain better results. This is only possible if these methods allow separate investigation of the performance of the different components and enable him to trace the influence of any alteration.

Applying this to the rocket motor means that first we have to separate the components which can affect the specific impulse. This includes not only structural components, but also, for example, kind of propellants, mixture ratio, etc. All these features are inter-related and the matter is therefore quite complex and not easy to sort out. Nevertheless we have to try to clarify it as far as is possible with available methods of measurement. It is useful to divide the influencing factors into two groups:—

I. Working conditions:
   Kind of propellants;
   Mixture ratio;
   Combustion chamber pressure.

II. Design features:
   Burner head (distribution and mixing system);
   Size and shape of the combustion chamber proper;
   Expansion ratio and shape of venturi.

Changes in these features can influence the performance remarkably; now we have to find out the tendency and order of magnitude of these influences. For this purpose it is necessary to obtain at least a rough picture of the process in a rocket motor.

We assume an ideal mixture of two gases, able to react together, *e.g.* hydrogen and oxygen, entering one end of the combustion chamber where it ignites at once. We know that there is always a delay between ignition and proper reaction, even if it is very small, and further that the reaction itself takes a certain time. A reaction zone of a certain length is required, beginning at a certain distance from the gas inlet (fig. 1). In this zone the chemical energy is transformed into a form of energy which we call heat energy. How this happens is a thing we do not know, but there is some evidence that in the first instant the whole of the chemical energy develops into translatory, or in other words, kinetic energy of the new molecule formed by the reaction. This translatory velocity $\sqrt{\bar{c}^2}$ of the molecule can result, for example, from the mechanical reaction effect of one or more electrons released with very high velocity from the outer electron shells of the atoms involved in the process. The molecular motion can have any direction; the average kinetic energy of one molecule $\frac{1}{2}\mu\bar{c}^2$ is what we call temperature. During their time of stay in the chamber the molecules are involved

in a number of impacts against each other and against the wall; the total impact effect of all molecules against unit wall surface is measured as pressure. The repeated impacts of the molecules against each other, however, cause a drop of the translatory energy due to eccentric and oblique impacts, etc., which excite rotation of the molecules about their centre of gravity and vibrations of the atoms within the molecules. Rotation and vibration represent a new form of energy which must have been taken from the former translatory energy thus decreasing the amount of this kind of energy. A further consequence of impacts is dissociation. If the energy transferred to a molecule by an impact is equal or higher than the bond energy between the atoms forming it, this molecule splits up again into the former components with equivalent loss of translatory energy.

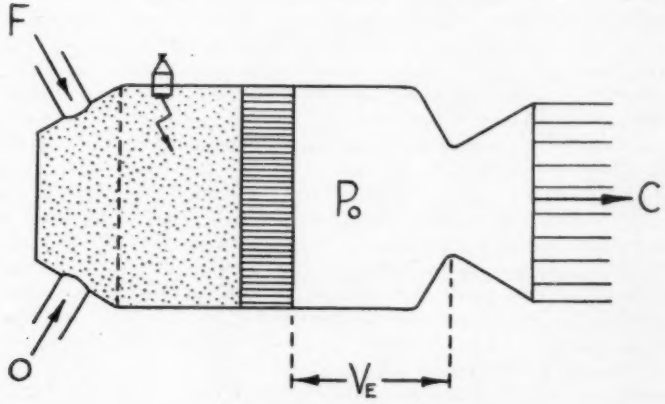

FIG. 1

All these secondary processes, however, need a certain time. If the time given to the process is long enough it reaches a state of equilibrium which is dependent on temperature, gas combination and, for dissociation, perhaps pressure. Neglecting dissociation, the specific molar heat provides a good means for determining the energy distribution. In the equation

$$C_v = \frac{1{\cdot}98\,f}{2} \simeq f$$

C_v is a symbol for the heat which one mol. of the gas needs for a rise of 1° C. at the temperature considered at constant volume and f gives the number of degrees of freedom of motion excited at this temperature. For a true gas the minimum of f is 3 because there are always the 3 degrees of freedom for translatory motion. With rising temperature, rotational degrees of freedom, 1 to 2 for diatomic molecules and 2–3 for triatomic molecules, are also excited; with further increase of temperature more and more vibrational degrees of freedom are added. Each degree of freedom requires nearly the same amount of energy (law of equipartition), *e.g.* if 8 degrees of freedom are excited, that means $C_v = 8$, the

3 translatory degrees contain $\frac{3}{8}$ of the total energy in the gas. Only this portion $\frac{3}{8}$ will be indicated by a thermometer. The other part $\frac{5}{8}$ is not felt as the temperature because it represents no kinetic energy.

Let us now consider the effect of a hole at the downstream end of our chamber. The molecules moving in the direction of the hole find no resistance, so that gradually all molecules obtain a common velocity in the direction of and through the hole. By attaching a divergent nozzle to the hole, which works as a sort of reflector for molecules still having lateral velocity components, we obtain at last a state in the gas flow where all molecules have the same direction at an average velocity which represents the former translatory energy in the unorganised gas. The temperature measured by a thermometer moving with the gas at the exit, in such an idealised case, is absolute zero, the pressure against the wall of the venturi zero absolute as well. The total of the translatory energy of the molecules works now in a useful direction and develops the required thrust by reaction against chamber and venturi.

In the ideal process just described it would be possible to obtain the proportion of kinetic energy developed, from the amount of chemical energy used, by means of measuring the temperature in the combustion chamber at a spot where the equilibrium of energy distribution is reached; this means very near the throat of the venturi. The temperature gives us the product $\frac{1}{2}\mu\bar{c}^2$; if the average molecular weight of the gas is known we can thus obtain $\sqrt{\bar{c}^2}$, which is the exhaust velocity at infinite expansion. The actual magnitude of c depends then only upon the efficiency of the venturi. Thus it would be possible to trace the influence of any alteration in design, choice of propellants or mixture ratio, pressure, etc., independent of venturi features.

In the foregoing, we assumed the time of stay in the combustion chamber to be long enough for reaching equilibrium. We now have to consider the case where this condition does not exist. Here only a certain number of the additional degrees of freedom can become excited before the molecules pass through the outlet which means that a greater portion of the original translatory energy is saved. The same applies to dissociation. Assuming an ideal mixture of the gases before reaction we may consider the case where the complete reaction takes place in a very narrow zone just in the plane of the throat. Provided that there is only negligible secondary excitation in the venturi itself the gain in kinetic energy at infinite expansion must be equivalent to the chemical energy expended, which means that η_E and η_S equal 100 per cent. The chamber has still a certain volume, that is, the volume needed for ignition and reaction delay, but the volume after completed reaction, which we shall call effective volume V_E, is zero.

If we wish to make a temperature measurement in this case, it is clear that there is only one position for the thermometer which gives the correct result, that is very close to the throat. But here there exists already a high gas velocity. We must remember that the thermometer always indicates the average kinetic energy of the molecules, but not the number of these molecules (provided its heat capacity is zero). It will, therefore, show the correct temperature at the upstream side, but a lower one at the downstream side; this effect will be increased in a real thermometer which always has a certain heat

capacity and uses some heat energy for the indication itself, *i.e.* the measurement is influenced by heat conductivity. The temperature indicated is therefore always lower than the true temperature; thus temperature measurement cannot be used for evaluation of I_s and η.

The same applies to all intermediate cases between these two extremes, *i.e.* for the actual rocket motor. If we calculate the average time of stay of the combustion gas for some of the chambers produced in the past, supposing that the complete reaction has taken place near the burner head, we obtain values between 3×10^{-3} to 5×10^{-3} sec. The actual time of stay after reaction is completed is much smaller because the reaction continues throughout the chamber. At best only a very small number of the molecules react near the burner head; most of them need some time in the chamber for good mixing and preparation for ignition (time for evaporation and decomposition) and a certain number leave the chamber unburnt. There will, therefore, be no great error if we assume the actual time of stay for the average molecule to be about $0{\cdot}5 \times 10^{-3}$ to 1×10^{-3} secs. The question is now whether this time is enough for establishing equilibrium between all degrees of freedom which can be excited at our working temperature. The answer seems to be: No.

During the determination of specific heat values in hot gases by means of sound waves, where it is necessary to measure temperature and pressure amplitude in the wave, the results obtained do not agree with the values of C_v, obtained by the usual stationary methods. The new value is much smaller. The explanation is that the time for sound transmission is too short to excite all degrees of freedom obtained under stationary conditions as in bomb calorimeter tests. Particularly the vibrational degrees of freedom need an unexpectedly long time for excitation.

Supposing a sound frequency of 500 c.p.s. for the test just described, the compression time for one cycle is $\frac{1}{2} \times 2 \times 10^{-3} = 1 \times 10^{-3}$ sec.; assuming further a comparatively low gas temperature in this test and the time for obtaining equilibrium being inversely proportional to the sound velocity, which itself depends on temperature, we may guess for our case with about twice the sound velocity that the same state of energy distribution as in the above-mentioned test is reached after about $0{\cdot}5 \times 10^{-3}$ sec., which is of the same order of magnitude as the actual time of stay in the chamber. This leads to the conclusion that even in a normal chamber, the state of energy distribution between the molecules at the throat is far from the equilibrium state. This statement refers to the average molecule and does not exclude some molecules being under or over-excited. This applies to dissociation as well, but to an even higher degree, because impacts effective for dissociation occur much more rarely than impacts leading to excitation of, for example, vibrational degrees of freedom. The amount of dissociation to be expected in such a chamber can therefore be only small. It cannot, however, be avoided that a certain quantity of propellant molecules do not react at all or only partly before they leave the chamber.

Any alteration in the size of the chamber for the same throughput has thus two opposite effects; decreasing the volume leads to saving of kinetic energy by avoiding excitation of undesired degrees of freedom, but the quantity of the unburnt propellants increases. For every rocket motor design and every

propellant combination there must exist an optimum chamber volume where the two kinds of losses reduce to a minimum. We have some evidence that enlarging a chamber has just the opposite effect to that expected; instead of improving the results by cutting down the amount of unburnt propellants the value of I_s drops. This has been found in practice, for example, during development of the V.2 chamber.

What are now the conclusions the designer has to draw?

1. The only way for suppressing excitation of undesired degrees of freedom and thus saving as much kinetic energy as possible is by reducing the effective volume V_E of the chamber.

2. Increased losses by unburnt molecules obtained by such reduction must be cured by other means. These are for instance:

(*a*) Improving the mixing of the propellants by suitable design of the burner head.

(*b*) Suitable choice of propellants. Those which need a comparatively large amount of heat for evaporation and decomposition, such as nitric acid or some fuels, are not the best for this purpose, because the necessary heat can only be supplied from the combustion gas, which requires heat transfer to the unreacted constituents and therefore time. It may prove that alcohols and fuels consisting of cyclic molecules are better than those consisting of chain molecules; self-igniting mixtures may be preferable to non-self-igniting ones. It may further be useful to try the possibilities of catalysts for cutting down ignition delay and reaction time.

Should it be possible to suppress by these means at least the vibrational degrees of freedom, the loss of kinetic energy would then equal the rotational energy only, *i.e.* energy for rotation in 2 degrees of freedom for diatomic molecules and CO_2, and three degrees of freedom for other triatomic molecules such as H_2O. Combustion gas consisting of CO_2 only allows 3/5 of the chemical energy to be gained as useful kinetic energy; pure H_2O gives $3/6 = \frac{1}{2}$. A mixture of these gases produces a mean value between the two limits according to the mixture ratio. Under such circumstances a high CO_2-concentration shows some advantage. Assuming a theoretical specific impulse $I_{s_{th}}$ of about 400 for propellants used at present, it should therefore be possible to obtain for the specific impulse at infinite expansion I_{s_∞} values between 310 and 280 resulting in practical I_s values of 240 to 220 at sea level for normal combustion-chamber pressures. Further increases are to be expected by use of mixtures with a higher energy content such as pure alcohol and oxygen or methane and oxygen.

Now we have to find a method of measuring the effects of alterations as mentioned above. A suitable method has to cut-out the influence of the venturi because it introduces its own efficiency which is dependent on its shape (expansion ratio) and combustion-chamber pressure. A simple measurement of thrust and throughput therefore will never indicate separately the influence of alterations in the chamber proper. Temperature measurement is no solution either. Also we have to face the fact that the thermometer measures only the

local temperature and not the average value across the considered area in which we are interested. The difference between local and average temperature should not be underestimated; it is due to uneven propellant distribution and mixture ratio, a problem with which we shall have to deal again under the heading of heat transfer.

A gas kinetic consideration offers a solution. We know that the pressure gives a measure of the number times kinetic energy of the molecular impacts per unit area per second. The throughput, however, indicates the number of molecules involved; thus it must be possible to evaluate the average kinetic energy of a simple molecule by combining the two results. It is easy to understand that, as an example, constant pressure at decreased throughput, which means decreased number of molecules per unit volume and unit time, shows that the kinetic energy of the single molecule has increased. It can be shown that the following relation exists:

$$\frac{w}{A_t} = \text{const.} \sqrt{\frac{1}{\tau}}\, p_o$$

where $\frac{w}{A_t}$ = throughput weight per sec. per unit throat area;

p_o = combustion chamber pressure

and τ represents a measure for kinetic energy per unit mass of a molecule.

The value $\sqrt{\tau}$ is directly proportional to the specific impulse for infinite expansion I_{s_∞}; τ should therefore be as high as possible. It gives a true mean value which averages all local inequalities in mixture ratio and takes into account dissociation, energy loss by excitation of undesired degrees of freedom and quantity of unburnt propellant. For example τ is about 280 in the case of the V.2 chamber. If it were possible to evaluate τ by simple test procedure we would then have a means of tracing the influence of any alteration upstream of the venturi; to derive the related I_{s_∞} and, by measuring the thrust, to obtain the efficiency of the venturi separately. Looking at our equation for τ we see that it is only necessary to measure the throughput per second and the chamber pressure; and knowing the area of the throat, we have all factors needed to calculate τ and further I_{s_∞}. This then gives a measure for the performance of the tested chamber, assuming a venturi for infinite expansion and no back pressure—independent of the actual venturi used in the test. We should get the same result without a venturi, using only a simple orifice. If a venturi has been used and we want to know its efficiency we must measure the thrust of this arrangement, thus obtaining the actual I_s; dividing this by I_{s_∞} we get the venturi efficiency.

The whole test procedure reduces then to measurement of throat diameter, chamber pressure, throughput and thrust; for high accuracy it is useful to add measurement of atmospheric pressure. The first and last measurements are easy; the difficulties in measuring the other values do not arise from the type of measurement itself, but from the accuracy required. It is not sufficient to obtain mean results for one complete firing because starting and stopping time

always introduce quite an appreciable error; we have to aim for sets of instantaneous readings. For this purpose the gauge readings can be photographed altogether if the gauges are mounted as close as possible to each other on one common panel. This is probably still the method of obtaining the most accurate results. Another method is to use a multi-channel recorder. Both methods offer no particular difficulties to adaptation for pressure measurements; with some care in calibrating and handling the instruments it is always possible to obtain sufficient accuracy. The same applies to thrust measurement, particularly if the pick-up for the thrust consists of a fluid-filled cylinder closed one end by a diaphragm through which the reaction force of the chamber is transmitted, thus causing a rise in pressure in the enclosed fluid which is measured by a pressure gauge.

This arrangement requires a floating suspension of the chamber in the direction of thrust, *e.g.* by mounting it on a pendulum (fig. 2). The travel required for measurement can be reduced to 1 mm. or less if care is taken to keep the amount of air enclosed in the measuring device as low as possible ($\frac{3}{4}$—1 cm.^{3}). Errors introduced by deviation of the centre of gravity of the system from the true mid-position can then be neglected, additional forces caused by bending the feed pipes which lead from the stationary tanks to the pendulum arrangement are kept as small as possible. If, however, these pipes are carrying pressurised propellants, *i.e.* in all cases where fuels are supplied from pressurised tanks or pumps not mounted on the pendulum, a further error is introduced. It is the Bourdon effect which occurs in curved parts of the pipe system and can be negative or positive dependent on the direction of the bends. Here it is necessary to carry out calibration tests with the system pressurised before using it. This should be done at various pressures, but the propellants need not be flowing.

We have now to consider the last of our tasks: throughput measurement. It is the worst of all and we can say that there is still no generally satisfactory solution. The method common for other internal combustion engines which consists of measuring the time for emptying a calibrated tank containing a certain volume of fuel is not applicable for the comparatively tremendous throughput in rocket motors. The normal running time during which the whole contents of the main tanks is used very seldom exceeds 30–60 secs.; thus we have to use our main tanks, that is, we have to fit a device to the main tanks which allows to observe the fluid level, either using a communicating glass tube, a float, a resistance wire in the liquid, etc. All these methods need a tank of cylindrical shape with a large ratio of length to diameter if fairly accurate results are expected; some constructional difficulties arise if the tanks need to be pressurised. A further disadvantage is that we measure change in volume; for obtaining the required value in weight we have to measure density as well.

Another method is taking the change in weight of the total tank directly; the tank is mounted so that it can move in a vertical direction. Its weight is supported by a spring or a liquid-filled cylinder-bellows arrangement, the deflection of the spring or the pressure generated in the other device then gives the weight of the tank plus the contents at any instant. Subtracting the known weight of the empty tank we obtain the weight of the propellant. This method

is sufficiently accurate provided that friction is kept small by a careful design and the liquid weight is not too small compared with the dead weight of the structure. The arrangement, however, is fairly complicated and clumsy and needs careful maintenance.

Both the methods described have a common disadvantage; they do not measure the throughput per unit time directly, but the state in the tank at a certain instant. It is necessary therefore to trace a curve of the change in weight against time either by measuring in small intervals during the test and later drawing the curve or better by automatic recording during the test. The required throughput at a certain time can then be evaluated from the curve.

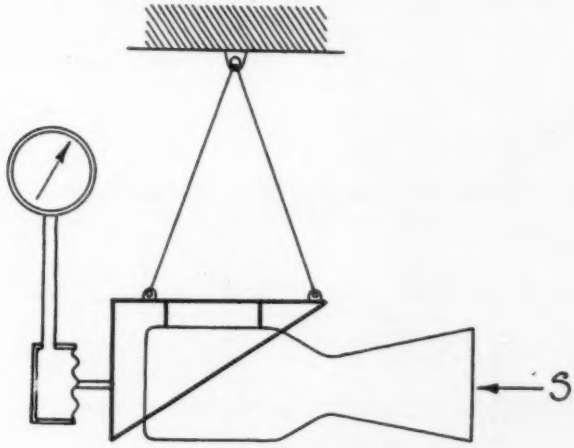

FIG. 2

Other methods are based on dynamic processes during the liquid flow in a pipe. We consider here only two out of the numerous methods used in general engineering practice.

The first method uses a Pitot tube for measuring the flow velocity in a pipe of a known diameter; the throughput is related to the velocity by the equation:—

$$w = \rho \frac{\pi}{4} d^2 v_m$$

with d = pipe diameter;

v_m = average flow velocity across the diameter;

ρ = fluid density.

It is well known that the velocity distribution across a tube is not even (fig. 3). If, for example, we fit the Pitot tube in the centre, we shall obtain the maximum velocity which when used in the equation would lead to a throughput higher than the true value. It is, of course, possible to calibrate the device, thus co-ordinating measured velocity to measured true throughput, but such a

calibration curve will be true only if density, viscosity and flow pattern in the tube at the point of measurement remain unchanged. The greatest source of error is the sensitivity of the Pitot tube to small variations of the flow direction. The method therefore is not very reliable.

The last method to be mentioned is to measure the pressure drop caused by a restriction, *e.g.* an orifice plate, fitted into the tube. Without friction we have

$$\triangle p = \frac{\rho}{2g} v^2_m$$

Measuring $\triangle p$ across the orifice plate and the density ρ we can derive v_m which, introduced into the previous equation and using the effective diameter of the orifice, allows us to calculate the throughput w. The effective diameter does not equal the true orifice diameter, it is always slightly smaller due to the contraction effect. Its influence cannot easily be forecast. For good accuracy it is therefore again necessary to carry out calibration tests with this arrangement; the results of the calibration are true only for the same density and viscosity. Sensitivity to changes in flow pattern is not so pronounced as with the Pitot tube.

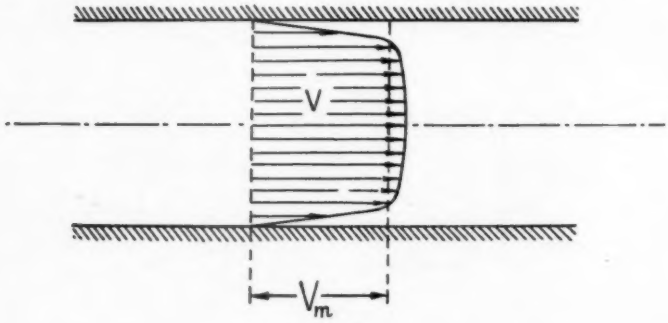

FIG. 3

The dynamic methods have the advantage of giving the throughput per unit time directly without further operations. They are not quite so accurate as the static methods; a further disadvantage is that they are not applicable to boiling liquids such as liquid oxygen, where density and viscosity are not constant and gas bubbles may occur.

The method chosen for measuring throughput is therefore dependent on kind of propellants, kind of feeding system and the arrangement of the test stand, but there should be no particular difficulty in obtaining the accuracy required. The measurement, of course, must be carried out for each propellant separately. Thus, we also obtain the mixture ratio.

Applying the measurements mentioned we obtain the following data:

Atmospheric pressure;

Combustion chamber pressure;

Throughput;

Mixture ratio;

Thrust;

I_{s_∞}, η_{s_∞}, η_{E_∞};

Venturi efficiency;

I_s, η_s, η_E,

which are sufficient for the thermodynamic part of rocket motor development.

Additional direct measurement of combustion chamber temperature and gas velocity might be useful, at least as a cross check. Considering temperature first, we should be aware that, apart from instrumental difficulties, the result of such a measurement can be very misleading for reasons already mentioned. Furthermore, we have to use the thermodynamic measurement of temperature in all our equations. All methods based on radiation for measuring temperatures are at least doubtful. Measuring gas velocity is not yet possible. If in the future an accurate method for obtaining the average gas velocity across the jet should be developed, it could be used as comparison for results obtained otherwise.

II

Heat Transfer and Cooling

The second problem of dominating importance in rocket motor development is control of temperature, *i.e.* the question how to construct a rocket motor which will stand even the highest gas temperature we can expect from using propellant mixtures of high energy content.

It is well known that at present we are not in the position to use with safety the more energetic propellants, such as pure alcohol or petrol with liquid oxygen, because of the possibility of burning through the inner shell when we try to use the propellants as a coolant. It is, however, just possible to do so if the coolant is supplied from an outside source with no limit on quantity and pressure drop across the cooling jacket, but this method of cooling is restricted to investigations on a test stand and not applicable to rocket motors for practical use. Here we are confined to internal cooling by the rocket motors' own propellants, which have a restricted heat capacity determined by the boiling point and the throughput of the coolant.

To clarify our views about the conditions of heat transfer in a chamber we will imagine some simple experiments.

Let us consider the chamber as being a simple tube through which pass combustion gases with a certain velocity, the tube being insulated against heat loss to the outside. We see that after a very short time the tube has reached the temperature of the gas, thus reducing the heat transfer between gas and wall to zero. It is clear that no metal would stand such a temperature (about 3,000° K.); even certain metal oxides or carbides which have high melting points would soften and so would not stand the gas pressure for long.

We now fit a second tube of slightly greater diameter concentric to the gas tube maintaining an annular free space between the tubes through which passes water at a certain velocity. The water now cools the inner tube, the quantity of heat taken by the coolant from the wall being the same as the amount of

heat transferred from the gas to the wall if the system is in equilibrium. Heat transfer, however, can occur only if a temperature gradient exists between two media; the gas temperature has not risen, consequently the wall temperature of the gas side must have dropped. The wall material also has a resistance against heat transfer which means that we have a temperature drop across the wall. For heat transfer from wall to coolant there is again a temperature gradient between outside wall and coolant.

If the water stagnates in the jacket it will heat up to the boiling point and then start to evaporate to the outside space provided a connecting orifice is fitted to the jacket. The latent heat of evaporation per unit of weight water multiplied by the weight of water used per unit time gives the rate of heat removal. Such a system is possible, but not very reliable; steam bubbles which develop on the coolant side of the inner wall tend to stick to the surface and cause after a short time overheating at this spot, due to the bad heat transfer across the stagnant steam. Further the method is not economical because the steam produced means loss and therefore represents propellant consumption without efficiency.

This leaves us with cooling by circulation so that the coolant becomes heated to a temperature just below the boiling point at the coolant pressure used, this temperature being reached at the coolant outlet.

The proper heat transfer between wall and coolant is restricted to a very thin layer of the fluid, the boundary layer at the wall. This would come to the boiling point after a few cms. if no liquid exchange took place between the boundary layer and the rest of the fluid. This, however, fortunately occurs to a fairly great extent due to turbulence caused by the existence of shear and friction forces within the liquid. The turbulence shifts the hot liquid near the wall into the cooler parts of the channel and replaces it by cold liquid which in turn rises in temperature. With sufficient turbulence the water is at a fairly even temperature when it leaves the jacket provided that the width of the cooling channel is not too great. The magnitude of turbulence is influenced by the flow velocity.

By adjusting the flow velocity in the cooling channel we can reach a point where the coolant temperature at outlet has the critical temperature just below boiling point. This represents a temperature rise in the liquid, $\triangle t$. The heat transferred under this condition per second is

$$Q = c_m \triangle t w_c \text{ cal./sec.}$$

where c_m = mean specific heat of coolant between inlet and outlet temperature

w_c = throughput of coolant in weight/sec.

In our case w_c is now fixed by the area of the channel and the flow velocity. This latter is chosen to give the maximum possible outlet temperature.

If the temperature at the inner side of the wall is still too high for the wall material, we can increase the width of the channel, thus increasing the throughput at the same flow velocity, provided that there is no restriction in the coolant supply. It may be necessary to readjust the flow velocity because the turbulence is to some degree influenced by the shape of the channel section, again aiming for critical temperature at the outlet. We can go ahead with

widening the channel until we reach a point where further increase of channel width does not improve the heat transfer. The turbulence is not sufficient to maintain an even temperature across the channel.

For this experiment we assumed the inner wall being a simple tube and the gas having always equal density and temperature. Our actual "tube," however, has changing diameter and the gas varies in density, velocity and temperature along the axis of the chamber. What is the influence of all these changes on the local heat transfer? Let us consider first the heat transfer caused by convection, *i.e.* heat transfer due to molecular impacts against the wall.

It is easy to see that for a tube of smaller diameter we have to remove less heat to obtain the same conditions, because the surface is smaller. Further, lower gas temperature requires less heat transfer for keeping the wall temperature the same, due to the smaller temperature gradient between gas and wall. Similarly, lower density of the gas leads to smaller heat transfer; here the effect is caused by decrease of the number of molecules pushing against the wall during unit time, the total of the impact energy lost to the wall being the heat transferred to it. Lastly, change of the gas velocity has an influence on the magnitude of the turbulence, and therefore on the temperature exchange between boundary layer and the rest of the gas resulting in a similar effect on heat transfer to that at the coolant side of the wall, this being valid at least for subsonic gas velocity.

The second method of heat transference to the wall is radiation which adds to the convection heat. Gas radiation in general is not very strong, but it differs very much with the kind of gas. In the combustion gas mixtures generated from normal propellants, CO_2 and H_2O produce most of the radiation so that it is only necessary to consider them—apart from radiation of solid carbon particles which are always present if the combustion is not complete. The radiation heat transfer depends on the gas composition, density of the radiating gases in the mixture, temperature and thickness of the radiating gas body. It is partly cancelled by back radiation from the wall.

Lastly, we shall consider the influence of the wall material. For any solid material there exists a certain temperature beyond which the tensile strength begins to fall, at first slightly, then with further rising temperature more and more until the so-called softening temperature is reached, where the material is just not molten but is at zero strength. The inner wall of the rocket motor with its steep temperature gradient therefore shows a varying tensile strength across its thickness, which may be zero at the gas side of the wall, but at its maximum at the coolant side. The mean of the tensile strength curve across the wall is the value which matters for stressing. The load on the wall is due to the pressure difference between the coolant space and the combustion chamber; in nearly all practical cases this tends to collapse the inner wall. It is always possible to keep this pressure difference small by introduction of some control gear which prevents this difference ever exceeding the sum of the pressure drop across the burner head and the pressure drop across the cooling jacket. The required wall thickness then remains comparatively small—it is, of course, dependent on the chamber size, all else being equal. This gives one figure for the wall thickness—what happens if we increase the wall thickness?

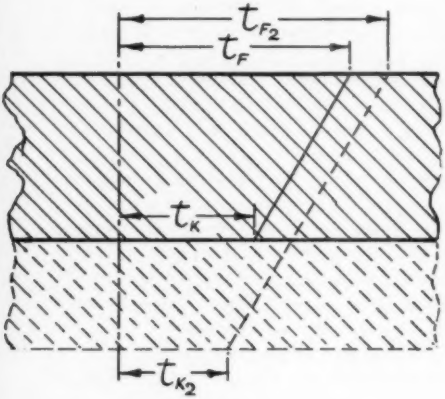

FIG. 4

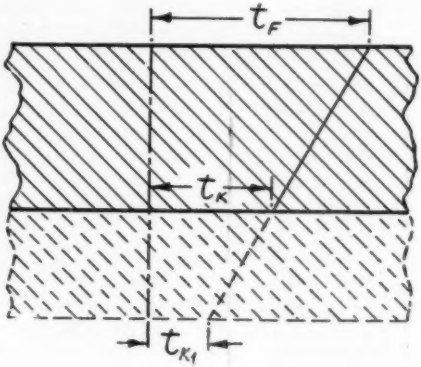

FIG. 5

The first consequence is that the rocket motor weight increases which is only desirable if we can gain something on cooling. Let us consider fig. 4, which shows a section of the wall.

At the gas side we have the wall temperature t_f, at the coolant side the wall temperature t_k for the original wall thickness. We suppose that t_f remains unchanged when we increase the wall thickness. The part of the temperature curve which connects t_f and t_k and which, for convenience, we assume as being a straight line, remains unaltered; the curve extends at the same inclination into the part of the wall thickness which we have just added, giving the new value t_{k_1}, as wall temperature at the coolant side. It is lower than the original value, which means that the temperature drop between wall and coolant and consequently the heat transfer from wall to coolant have decreased if the coolant velocity has not changed. The heat transfer at the gas side is as before (t_f = const.), therefore the equilibrium condition for heat transfer is not fulfilled; the temperature in the wall starts to climb until a new equilibrium is reached (*see* fig. 5); t_f has gone to t_{f_2}, t_k to t_{k_2}. The rise in t_f has one advantage; the heat transfer has been reduced so that for the same coolant velocity t_{k_2} is smaller than t_k. The mean wall temperature has certainly not changed very much; if we consider the mean temperature as significant for the mean strength, which is not quite true, the thicker wall is stronger than the original wall. At first sight this looks quite promising.

But if we introduce the condition that t_f at the thin wall already represents the limiting value, thus not allowing a further increase, we can use the thick wall only if it is still possible to maintain the heat transfer at the coolant side by increasing the coolant velocity. This leads to the conclusion that the thinner wall requires a lower coolant velocity and therefore is to be preferred.

To complete the picture, we shall look finally at the effect of change of wall material. From the above we must conclude that the heat transfer should be

kept as small as possible because the cooling capacity of the coolant is very restricted where the propellants are used as a coolant. The means of reducing heat transfer is to cater for only small temperature differences between gas and inner wall, which we can do only by choosing a wall material with a high softening temperature and good tensile strength at high temperature. It is as well also to have a high thermal conductivity which makes the temperature gradient across the wall smaller and consequently raises the outer wall temperature, thus providing a better heat transfer to the coolant. Unfortunately, the materials with high melting point and good tensile strength at high temperature have a rather poor thermal conductivity.

For all these reasons heat resistant alloy steels seem to be the most suitable materials; the development of non-metallic materials with exceptionally high melting points such as some metal oxides and metal carbides is not yet far enough advanced to be considered. They still tend to crack under thermal shock and are not easy to manufacture in the required shapes.

Applying all the foregoing considerations to an actual rocket motor, we conclude first that the heat transfer per unit wall surface must change very much along the axis. The most dangerous spot is located very near the throat on the upstream side, which needs the highest cooling intensity. The best use of the wall material is made if the wall temperature at the gas side is equal along the axis and is at its highest permissible value. It should be possible at least to approach this ideal by adjusting the coolant velocity, *i.e.* the channel cross area, to the local requirements.

To do this, systematic investigations must be made. The existing heat transfer theory is not able to give the required information. Particularly at the gas side the conditions differ considerably from those for which the existing formulae have been developed. The gas temperature in a rocket motor is about twice those usually considered and the gas pressure is much higher than pressures hitherto investigated. The formulae are not applicable at all for supersonic gas velocities. A further difficulty in the calculations arises from the fact that the gas temperature shows local differences because the burner head never produces an ideal mixture distribution. Depending on the mixture ratio actually present gas streaks of high or low temperature develop which in general persist at the same position—at least during one run. If a streak of high temperature touches the wall even for a short time, it causes overheating at this spot in spite of sufficient overall cooling for the total mixture. We have to watch this effect during the heat transfer investigations.

The first task is to find out the heat flow through the wall and its changes along the motor axis under different conditions, which is possible by measurements at the coolant side only. A total heat transfer measurement for the whole rocket motor is of no value in clarifying all effects methodically. It is, therefore, necessary to build up a general test arrangement which allows investigation of single zones of the motor, using water as a coolant for convenience (fig. 6).

The cooling jacket is split up into separate annular channels, each having its own inlet and outlet pipe, so that it is possible to measure the coolant throughputs through the channels independently, together with inlet and outlet

temperature of the water. From this data we obtain the heat taken from that portion of the inner wall surface which is cooled by the channel considered.

We know that the heat transfer is dependent on the temperature drop between gas and wall; for obtaining the nominal heat flow which the wall material allows we have to adjust the temperature of the gas side of the inner wall to the highest possible value. This can be done easily by altering the coolant throughput by means of throttling valves fitted to the coolant supply pipe of each channel. The wall temperature is taken by means of thermocouples. It is now possible to adjust all throttling valves so that the wall temperature in

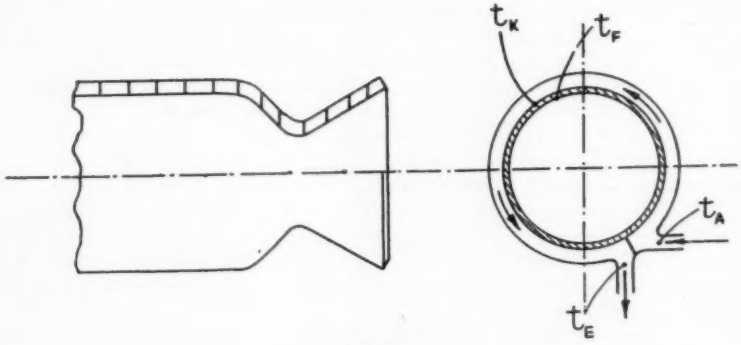

FIG. 6

all channels is the same and at the limiting value; the quantity of heat per second transferred to the coolant of one channel under these conditions divided by the inner wall surface of this section gives the mean heat transfer in cal./cm.^{2} sec. for the section. Plotting the results for all sections against position of the sections along the axis of the rocket motor, we obtain a curve showing the variation of heat transfer along the motor; by integrating we obtain the total heat transferred. This curve is valid for one state of the combustion gas indicated by p_o and τ. Using the same chamber, burner head and propellants at the same mixture ratio we keep τ constant; thus by varying the pressure we get a family of curves for heat transfer dependent on p_o only, a result which covers the heat transfer features for our chamber design, using a certain propellant combination. We now are able to decide at least roughly whether it is possible to run this rocket motor under practical conditions, *i.e.* with the coolant proper. In general, this has to be one of the propellant components; we know its physical properties, such as specific heat and boiling point at the pressure used, and the quantity available for the design considered, which information gives us the cooling capacity for various chamber pressures. Comparing with the test results it is now easy to find the maximum pressure at which the rocket motor can just run safely. If we should find that this pressure is too low, it is then necessary to decrease τ by reducing the heat content of the propellants, *e.g.* by diluting one of the components with water, using another fuel, etc. This

has a bad effect on the specific impulse; it would therefore be better to decrease the inner wall surface area of the rocket motor by altering the design, if this is possible. It will not be, however, if the chamber size has been fixed by the thermodynamic tests described in Chapter I.

Having now established the maximum values of p_o and τ, we are left with the task of finding the correct coolant velocity distribution along the rocket motor, or, which comes to the same, the correct cooling channel area. The coolant velocity derived from the tests described above, cannot be used for the actual rocket motor for two reasons: (1) the propellant used as coolant has physical properties differing from those of water, (2) the shape of the cooling channel in the actual rocket motor is quite different. Here the coolant flows parallel to the motor axis; furthermore, the cross-sectional area of the channel varies along the channel and has a quite different ratio of height to width. Another disagreement exists in comparing the radius of channel curvature and the direction of curvature related to direction of flow; this causes varying degrees of turbulence.

Because of the lack of systematic investigations we are again not able to solve the problem by calculation; it is not possible even to transform the test results obtained during the previous investigations to the new conditions in the actual design without doing some basic tests which will now be described.

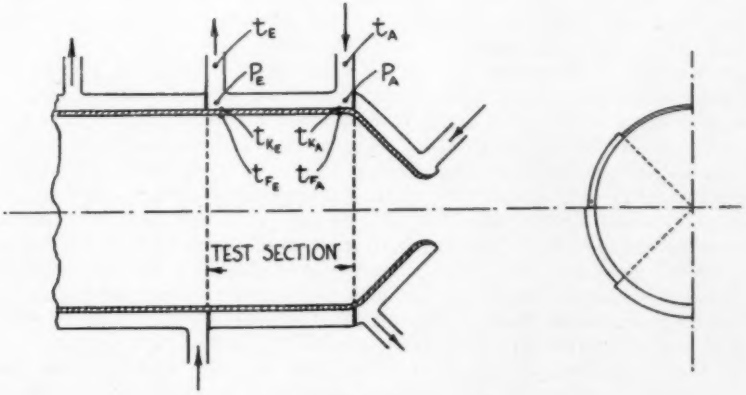

FIG. 7

We again need a specially built test apparatus which should resemble the first design as far as possible (fig. 7). For the actual rocket motor the cooling jacket is divided into a number of channels for two reasons. The inner wall is held in position by some spacers arranged between outer and inner wall in a direction parallel to the motor axis which automatically leads to a division of the jacket into parallel channels. More important, however, is another effect. If local overheating takes place it forms a steam bubble which tends to stick

to the wall and to grow. To avoid further overheating, this bubble should be removed as quickly as possible. If its dimension is small compared with the cross-sectional area of the channel, it causes only a small increase of the coolant velocity, *i.e.* small pressure drop across the affected length of the channel which may be not high enough to remove the bubble. It grows therefore until the displacement of cross-sectional area left to the flow is big enough to cause a pressure drop sufficient to shift the bubble. To avoid burning of the wall the bubble dimension should be kept as small as possible, which calls for a small channel cross-sectional area which is easily obtained by increasing the number of spacers to, say, 8–12 on the circumference.

The test apparatus should therefore contain the same number of channels as the practical chamber and furthermore use the same propellant as a coolant, which, however, should be supplied from a source independent from the propellant flow for combustion, thus allowing variation of the quantity used for cooling. The chamber should have a large cylindrical section, a part of which is fitted with the test channels. The channel length to be tested should begin quite a distance downstream from the burner head, thus assuring fairly complete combustion along the test section; it may extend right to the chamber exit. For these tests it is not necessary to have a venturi. Cooling of the parts of the chamber not used for test purposes may be done with water for convenience. The test section itself is cooled by the propellant proper and divided into about 8–12 parallel channels, each of them having their own coolant outlet and inlet pipe, the latter fitted with a control valve. To cover a certain range of conditions it is useful to give different widths to the channels. During the test we have to measure at least the temperatures of the coolant at inlet and outlet, gas side and coolant side temperatures of the wall at inlet and outlet points, all of these for each channel, and chamber pressure and propellant throughput.

The test procedure begins by adjusting to a certain chamber pressure which is to be kept constant during the series of tests. All coolant control valves are wide open to make sure that the chamber is over-cooled. We concentrate then on one channel by throttling the coolant supply gradually, always taking the required measurements until the limiting value of the gas side of the wall is reached. Repeating this for all channels and later for different chamber pressures we obtain curves for the heat transferred to the coolant per unit surface time and unit time. These depend on the wall temperature at coolant side, channel width and flow velocity.

The required temperatures at the coolant side along the wall are known from the previous tests; it is now possible to derive the necessary coolant velocity and the correct channel width, for the coolant throughput available, at any section of the rocket motor. The final rocket motor design thus obtained needs still a check test because the influence of channel curvature on turbulence may alter the performance a certain amount.

It is quite useful to measure the pressure drop across the cooling channels during these tests; if this has been done it is possible to forecast the total pressure drop caused by the cooling jacket which can have an important effect on the total project. High pressure drop means high propellant tank or pump pressure, which can be expressed either as increase in dead weight or decrease

of specific impulse of the total system. In certain cases it might therefore be more favourable to reduce the net specific impulse of the motor proper in order to ease cooling, thus decreasing the pressure drop caused by the cooling jacket.

The instrumental equipment for all these tests calls only for instruments which are in quite common use, with perhaps one exception—the flow-meters for measuring the coolant throughput which are required for each channel. Their range is small, but we need a number of them. The main difficulty is the high accuracy required. The coolant temperature measurements demand again very high accuracy which can be obtained only with resistance wire thermometers which have the further advantage of remote reading. Their disadvantage, slow response, does not come into account here, because we have to wait for stationary conditions in any case before taking measurements. Particular care is needed in the outlet temperature measurement; the situation of the thermometer directly at the channel end may falsify the result if the mixture between the hot boundary layer at the wall and the rest of the coolant is not completed. It is, therefore, better to introduce a mixing section between the channel outlet and thermometer which should be well insulated against heat loss.

Measurement of the wall temperatures can be done by thermocouples. Here it is necessary to use very fine wires to keep the heat capacity and the heat conductivity of the couple as small as possible. The hot junction is in a very small hole drilled into the wall as far as possible without penetrating it. This arrangement gives the temperature at the gas side, t_f. For obtaining the temperature at the coolant side it is sufficient to braze or spot-weld the hot junction to the wall. The difficulty in getting the required accuracy arises from the steep temperature gradient across the wall and the dimension of the wall thickness which may be about one-tenth of an inch. In particular the wires of the thermocouple for measuring t_f need very good heat insulation against the other part of the wall material and the coolant; only the junction proper should have contact with the wall and the size of the hot junction should be very small compared with the wall thickness.

As mentioned before, we have to be aware of the presence of hot streaks in the combustion gas which may touch the wall and overheat it in spots, thus faking our results if our wall thermocouple is located at such a spot. We remember that we are aiming for mean values in all these investigations. To avoid misinterpretations it is therefore necessary to arrange a number of wall thermocouples in each channel and take the mean value of all readings.

The whole test programme is not very easy; it calls for a great number of readings at the same time, which can only be done automatically and therefore needs a specially well equipped test stand.

In the foregoing we considered only indirect cooling across the wall. This method is in any case the most economical one, because the heat transferred to the cooling propellant is transmitted to the combustion chamber after all. But this method has a limit. It is reached when the required coolant velocity and consequently the necessary pressure head for obtaining this velocity expressed in upstream weight of pumps or tanks becomes so high that less economical cooling methods can compete. This remark refers to film cooling. It is based on the principle of drilling a number of fine holes through the inner wall, thus

connecting cooling jacket and combustion chamber directly. The coolant passes now through these holes into the chamber, evaporates under the influence of the hot combustion gas and, at the same time, travels along the wall accelerated by the gas flow, thus forming a vapour film between wall and gas of comparatively low temperature. The film protects a certain portion of the downstream surface of the wall against convection of heat from the gas. The quantity of coolant used for this purpose is, of course, lost because it develops only a small flow velocity compared with the combustion gas. It is, therefore, obvious that this method should be used only if there is no other possibility, *e.g.* in the case of local overheating caused by hot streaks. If such a spot is observed it is sufficient to drill a fine hole through the wall some distance upstream from the hot spot. The steam developed downstream then protects just the dangerous zone. Film cooling may with advantage be provided in the case where the cooling capacity for indirect cooling is just not high enough. Here film cooling has to assist indirect cooling at the section of highest heat transfer, *i.e.* the section near the throat, thus enabling us to use higher energy propellants than would be possible with indirect cooling only. But in any case indirect cooling must be considered as the basic method of cooling.

Another problem arises if the rocket motor is to be controlled over a certain range of thrust. How does throttling affect the heat transfer? Pressure and density decrease with reduced thrust, the gas temperature remains nearly constant, but the throughput of the propellant used as a coolant decreases as well, which not only affects the cooling capacity, but also the coolant velocity, because the channel cross-sectional area cannot be altered. How far it is possible to throttle a rocket motor down, developed for maximum performance at full thrust, cannot be decided with present knowledge. The investigations mentioned above, however, will bring to light sufficient information to fill this gap. But wherever this limit may be, if we want to throttle the thrust beyond this limit we have to find another way to attain effective cooling at such a low thrust by, for example, additional film cooling during low thrust only, or by circulating a propellant quantity for cooling which is larger than necessary for combustion, the excess being fed back to the main tank.

Summary

We cannot to-day solve the thermodynamic and heat transfer problems in rocket motor development by pure calculation, based on equations established for common engineering. The task needs a new approach in investigation and test work which will keep scientists and engineers busy for a number of years. No insuperable difficulty arises from the instrumental equipment to be used. Later it may be possible to derive at least empirical formulae from the results, which then would allow treatment of design work for a new rocket motor project in a manner similar to that of any other power plant to which we are accustomed to-day.

* * * *

PERTURBATIONS OF A SATELLITE ORBIT

By Lyman Spitzer, Jnr.,
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ABSTRACT

The motion of a small body, revolving in a nearly circular orbit around the Earth about 800 kilometres above the Earth's surface, is considered. Perturbations by the Sun and Moon are negligible, causing the orbit to depart from a circle by less than one metre. Perturbations caused by the oblateness of the Earth are much larger. An orbit nearly in the plane of the equator will not be distorted appreciably, but will precess in space; the pole of the orbit will move in a circle about the celestial pole, taking 55 days for a complete revolution. An orbit passing over the poles will deviate from a circle by 1·5 kilometres, which is less than the deviations of the Earth's surface from a sphere; the body will be 18 kilometres higher above the Earth's surface at the poles than at the equator.

The orbit of a small satellite vehicle revolving about the Earth, in a gaseous medium so rare that its resistance may be neglected, is to a first approximation an ellipse, with the centre of the Earth at one focus. In this approximation the Earth is assumed to be spherical and the gravitational attractions of other bodies on the satellite are neglected.

Higher approximations may be found by the standard methods of celestial mechanics. In the present analysis these methods are applied to compute the orbit in a second approximation. Specifically, the magnitude of the perturbations produced by the Moon and Sun (Section I), and by the oblateness of the Earth (Section II) are computed to a first approximation, on the assumption that the satellite is in a nearly circular orbit. Numerical values are found for a satellite 800 kilometres above the Earth's surface. Since the perturbations produced by the Sun and Moon are shown to be very small, it is obvious that those produced by the other planets are wholly negligible. The only perturbations discussed here are the short-term deformation of the orbit and the steady motion of the orbit in space. Other perturbations are of higher order and may certainly be neglected during a time interval of only a few hundred years. A more elaborate investigation would be required to prove the stability of the orbit over very long intervals. For example, the stability of the solar system during a billion years has not been proved, since the series used for analysing the situation diverge after so long a time. While this question of long-term stability is of considerable theoretical interest, it has little practical importance and will not be considered here.

Symbols used a number of times in the following analysis are as follows:—

n Mean angular motion of the satellite relative to the Earth, taken as $1{\cdot}0 \times 10^{-3}$ radians/sec.

M Mass of the Earth.

M_M, M_S Mass of the Moon and Sun, respectively.

R Mean distance of the satellite from the centre of the Earth, taken as 7,200 kilometres.

R_M, R_S Mean distance of the Earth from Moon and Sun, respectively.

A Moment of inertia of the Earth about an equatorial radius.

C Moment of inertia of the Earth about the polar radius.

* This work was carried out while the author was at Yale University.

G Gravitational constant.
r Distance of satellite from centre of Earth.
ρ $r - R$, the deviation from circularity.
ω Angular rate of regression of the nodes (the points at which the orbit crosses the ecliptic or equator).

I. Perturbations by Moon and Sun

A distant body will exert an attraction on both the Earth and a neighbouring satellite. Thus both Earth and satellite will accelerate towards the distant body. The difference between the acceleration of the Earth and the acceleration of the satellite is the "disturbing acceleration" which perturbs the satellite orbit relative to the Earth. The magnitude of this acceleration may be computed very simply when the satellite is on the line joining the Earth and the Sun, at a distance R from the Earth. If the x axis is taken along the line joining Earth, satellite, and sun, then the acceleration of a satellite relative to the Earth is given by

$$\frac{d^2x}{dt^2} = \frac{GM}{R^2} - \frac{GM_S}{(R_S - R)^2} + \frac{GM_S}{R_S^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The sum of the second and third terms is the disturbing acceleration. Let ψ be the ratio of this acceleration to the earthward acceleration represented by the first term in equation (1). On expanding $(R_S - R)^{-2}$ and retaining only the first two terms, we have

$$\psi = 2\frac{M_S}{M}\left(\frac{R}{R_S}\right)^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

For satellite at a height of 800 kilometres, equation (2) gives $0{\cdot}73 \times 10^{-7}$ for ψ. For perturbations of the satellite by the Moon the corresponding value of ψ is $1{\cdot}6 \times 10^{-7}$. The value of ψ is approximately the ratio of the tidal force at the surface of the Earth to the gravitational force towards the Earth, and it is well known that the solar tides are about half the lunar ones, in agreement with the above result. In comparison, for the perturbations produced by the Sun's attraction on the Moon ψ is $1{\cdot}1 \times 10^{-2}$. While for a value of ψ as great as 10^{-2} the perturbations can become relatively large and complicated, for values as small as 10^{-7} one may expect these perturbations to be negligible.

First, the approximate deviation of the orbit from a circle will be computed. The shape of a satellite orbit perturbed by the Sun has been computed by G. W. Hill.[1] For the deviations of an orbit from circularity we have his result, expressed in the present notation,

$$\rho - Rm^2 \cos 2(n - n')\, t \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where n and n' are the mean motions of satellite and Sun, respectively, relative to the Earth, and

$$m = \frac{n'}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

In these equations, the many terms found by Hill in m^3 or higher have been neglected. The mean motion n of the satellite is given to a first approximation by

$$n^2 = \frac{GM}{R^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

which gives a value of $1{\cdot}0 \times 10^{-3}$ for n when R is 7,200 km., corresponding to a height of about 800 km. above the surface. Since also

$$n'^2 = \frac{GM_S}{R_S^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

we have for $\rho_{max.}$, the greatest value of ρ,

$$\rho_{max.} = \tfrac{1}{2} R\psi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Substituting the numerical values used above into equation (7), we have

$$\rho_{max.} = 26 \text{ cm.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Hill's theory cannot be directly applied to perturbations of a satellite by the Moon, since the Coriolis force and the disturbing force are no longer related in the same simple way as in the perturbation of a satellite by the Sun. However, examination of the basic equations in this situation show that equation (7) is still valid, provided that the value of ψ for lunar perturbations is used. Thus the perturbations by the Moon give a value of 57 cm. for $\rho_{max.}$ When the Sun and Moon are in conjunction or opposition, these values of $\rho_{max.}$ are directly additive, and we have

$$\rho_{max.} = 83 \text{ cm.} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

This resultant value is probably much too small to be measurable.

Next we must compute the rate at which the orbit plane precesses about the pole of the ecliptic. In this motion, the inclination of the orbit plane to the ecliptic remains constant. The pole of the orbit (the intersection with the celestial sphere of a line perpendicular to the orbit plane) moves in a small circle about the pole of the ecliptic, the direction of this motion being opposite to the direction in which the satelite revolves. Thus the nodes, or intersections of the orbit with the ecliptic, as plotted on a celestial sphere (*i.e.* as viewed from the centre of the Earth) move slowly backwards.

For perturbations of the satellite by the Sun, the results summarised by E. W. Brown[2] may be used. The angular velocity ω of this regression of the nodes is

$$\omega = \frac{3}{4}\frac{n'^2}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

or, using the relationships (5), (6) and (2) as before, we find

$$\omega = \frac{3}{8}\psi n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

If we substitute numerical values, we find

$$\omega = 2{\cdot}7 \times 10^{-11} \text{ radians/sec.} \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

This corresponds to a period $2\pi/\omega$ of 7,400 years.

For perturbations of the satellite orbit by the Moon, the conventional results are no longer applicable. It may be readily shown, however, that equation (11) is valid in this case also, provided that the appropriate value of ψ for perturbations by the Moon is taken. For example, equation (11) may be derived by a computation of the average torque L on the satellite, relative to the Earth's

centre, and use of the formula for precession of a gyroscope, which in this case becomes

$$\omega = \frac{L}{nmR^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

where m is the mass of the satellite.

Since the values of ω found for perturbations by the Sun and by the Moon are additive, we have, finally for the total luni-solar perturbations

$$\omega = 8{\cdot}7 \times 10^{-11} \text{ radians/sec,,} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

yielding a period of 2,300 years. It will be shown in the next section that this motion is overshadowed by a much more rapid motion resulting from the Earth's oblateness.

II. Perturbations by Oblateness of Earth

The motion of a particle of negligible mass in the neighbourhood of an oblate spheroid has recently been considered by Brouwer.[3] The gravitational potential U in such motion may be written approximately in the form

$$U = \frac{GM}{r}\left\{1 + k\left(\frac{1}{r^2} - \frac{3z^2}{r^4}\right)\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Where z is the co-ordinate of the particle along an axis parallel to the poles. The quantity k is defined as

$$k = \frac{C - A}{2M} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

where C and A are the moments of inertia of the Earth about the polar and equatorial radii, respectively.

The term in parentheses in equation (15) gives rise to a "disturbing acceleration," which again perturbs the orbit. Let χ be the ratio of this disturbing acceleration to the average acceleration, given by the first term, for a particle over the equator. If we differentiate equation (15) when z is set equal to zero, divide the second term by the first, and substitute for k from equation (16), we have, when $r = R$,

$$\chi = \frac{3(C - A)}{2MR^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

The value of C − A has been determined from gravity measurements in widely separated regions. Jeffreys[4] gives the result

$$\frac{3}{2}\frac{C - A}{Ma^2} = 1{\cdot}64 \times 10^{-3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

where a is the radius of the Earth. From this result it follows that

$$\chi = 1{\cdot}3 \times 10^{-3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

This ratio χ is about 10,000 times as great as the corresponding ratio ψ, and hence we may expect the perturbations produced by the oblateness of the Earth to be enormously greater than those resulting from the Sun and Moon.

First, we consider an orbit whose inclination to the Earth's equator is small. In such an orbit the disturbing acceleration will be nearly constant in magnitude and the orbit will be very closely circular. The mean motion n will be slightly greater than that given in equation (5), since the disturbing acceleration increases the inward force somewhat.

If such an orbit has a slight inclination to the equator, the pole of the orbit will move in a circle about the celestial pole. Thus the nodes, defined here as the intersections, on the celestial sphere, of the orbit with the equator, will regress in a direction opposite to the satellite's revolution. The magnitude of this effect has been analysed by Brouwer in reference 3. In the present notation we have, from his equation (35·2)

$$\omega = \chi n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

The higher order terms given by Brouwer are not considered here. If we subsititute numerical values, equation (20) becomes

$$\omega = 1{\cdot}3 \times 10^{-6} \text{ radians/sec.}, \quad \ldots\ldots\ldots\ldots\ldots\ldots (21)$$

yielding a period of 55 days, or about 770 revolutions of the satellite about the Earth. This effect could be readily observed.

Equation (20) was derived for small inclinations. When the inclination is large, the value of ω will be less than the value found above. By use of equation (13) the rate of regression of the nodes may be computed directly for arbitrary inclination. Such an analysis leads again to equation (20), but with the right-hand side multiplied by $\cos i$. Thus the period for the regression of the nodes will be proportional to the secant of the inclination, amounting to 78 days for an inclination of 45°.

As the inclination increases towards 90°, ω diminishes, and vanishes for an orbit passing over the poles. For such an orbit, however, the variation in the disturbing force will produce a deviation of the orbit from circularity. Since a situation of this type is unknown in the solar system, or elsewhere, orbits of this type have apparently not been analysed.

The perturbations may be computed to the first order by a relatively simple analysis in the case of a nearly circular orbit which passes over the poles. We shall let θ represent the angle which the line from the Earth's centre to the satellite makes with the equator; then $z = r \sin \theta$. The usual equations of motion in polar co-ordinates become, on differentiation of of equation (15),

$$\frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2 = \frac{\partial U}{\partial r} = \frac{-GM}{r^2} - \frac{3kGM}{r^4}(1 - 3\sin^2\theta) \quad \ldots\ldots\ldots (22)$$

$$2\frac{dr}{dt}\frac{d\theta}{dt} + r\frac{d^2\theta}{dt^2} = \frac{\partial U}{r\partial\theta} = \frac{-6kGM}{r^4}\sin\theta\cos\theta. \quad \ldots\ldots\ldots\ldots (23)$$

If equation (23) is multiplied by r, this equation may be written in the form

$$\frac{d}{dt}\left(r^2\frac{d\theta}{dt}\right) = -\frac{3kGM}{r^3}\sin 2\theta \quad \ldots\ldots\ldots\ldots\ldots (24)$$

As a first approximation we may replace r on the right-hand side of equation (24) by its mean value R, and let $\theta = nt$. Thus when $t = o$ the satellite is above the equator. Then by a simple integration we have

$$\frac{d\theta}{dt} = \frac{R^2}{r^2}n + \frac{3kGM}{2nR^5}\cos 2nt \quad \ldots\ldots\ldots\ldots\ldots\ldots (25)$$

The constant of integration in equation (25) is determined by the condition that on the average $d\theta/dt$ is, by assumption, equal to n. Throughout the

following analysis, r will be replaced by R in all terms which are of the first order in k. In terms of zero order in k, r is replaced by $R + \rho$ and terms in the first order of ρ/R are retained, since ρ/R and k are of the same order.

If equation (25) is substituted into equation (22), and r^{-2} and r^{-3} are expanded in terms of ρ/R, then to terms of the first order we have

$$\frac{d^2\rho}{dt^2} - n^2R + \left(3n^2 - \frac{2GM}{R^3}\right)\rho = -\frac{GM}{R^2} + \frac{3kGM}{2R^4}\left(1 - \cos 2nt\right) \quad \ldots\ldots(26)$$

The mean distance R of the satellite is related to the mean angular motion n by the equation

$$n^2 = \frac{GM}{R^3} - \frac{3kGM}{2R^5} \quad \ldots\ldots(27)$$

thus for a fixed distance R the mean angular motion for a satellite passing over the poles of an oblate spheroid is less than for a body revolving about a sphere of the same mass M. From equations (26) and (27) we find for ρ the following equation, including only terms of the first order,

$$\frac{d^2\rho}{dt^2} + n^2\rho = -\frac{3kGM}{2R^4}\cos 2nt \quad \ldots\ldots(28)$$

The following solution for ρ is readily obtained

$$\rho = A\cos nt + B\sin nt + \frac{k}{2R}\cos 2nt \quad \ldots\ldots(29)$$

In the derivation of equation (29), higher order terms in the coefficient of $\cos 2nt$ have been neglected. The terms in $\cos nt$ and $\sin nt$ represent deviations from circularity, corresponding to an eccentric orbit of the usual type; these terms bear no relation to the perturbation by the Earth's oblateness and will not be considered here. If equations (16) and (17) are used to eliminate k, then we have, finally,

$$\rho = \frac{1}{6}\chi R\cos 2nt \quad \ldots\ldots(30)$$

It will be noted that ρ is positive when $t = o$ and the satellite is over the equator. Thus the satellite is nearest to the centre of the Earth when it is over the poles. If we insert numerical values, we have for $\rho_{max.}$,

$$\rho_{max.} = 1{\cdot}5 \text{ km.} \quad \ldots\ldots(31)$$

This result may be compared with a difference of 21·4 km. between the equatorial and polar radii of the Earth. Since the satellite is 3·0 km. nearer the centre of the Earth when over the poles than when over the equator, the perturbations of the orbit partly counterbalance the varying altitude of the satellite above the Earth's elliptical surface. It is evident that the satellite will be 18 km. nearer to the surface of the Earth at the equator than at the poles.

REFERENCES

[1] Collected Works, *Memoir No.* 32; also *American Journal of Mathematics*, I, 5, 129, 245 (1878).

[2] *An Introductory Treatise on the Lunar Theory* (Cambridge University Press, 1896). *See* especially p. 130.

[3] *Astronomical Journal*, 51, 223 (1946).

[4] *The Earth, Its Origin, History and Physical Constitution* (Cambridge University Press, 1929). *See* p. 210.

NOTES AND NEWS

International Conference on Astronautics

Further to the report in the September, 1949, *Journal*, of discussions with the G.f.W. regarding a possible international conference on astronautics, readers will be interested to learn that it has been provisionally agreed that one should be held in London in September, 1951. Furthermore, by arrangement with the G.f.W., M. Ananoff, of the *Groupement Astronautique Francais*, is now making plans for a preliminary meeting of representatives of all interested societies, to be held in Paris from September 30 to October 2, 1950.

The Hermann Oberth Medal

The 1949 Annual Report of the *Gesellschaft für Weltraumforschung* (Stuttgart), which has just reached us, shows that this very active Society has made considerable progress in the first year. Many lectures and radio talks were given, and the membership now stands at 245 (30 of them outside Germany). During the year the following Honorary Fellows were appointed: Eugen Sänger, Willy Ley, Guido von Pirquet, Wernher von Braun, Otto Willi Gail, and A. V. Cleaver.

One of the most interesting items in the report is the announcement of the Hermann Oberth Medal, to be presented for outstanding services to astronautics. This has been established through the generosity of R. Oldenbourg, publishers of many important books on spaceflight, including Oberth's classic works. A silver medal will be presented yearly, and a gold one is reserved for special occasions.

The first recipient of this new award in astronautics was M. Alexandre Ananoff, leader of the *Groupement Astronautique Francais*.

The Hermann Oberth Medal.

M. Alexandre Ananoff, recipient of the first award of the Hermann Oberth Medal, 1949.

Professor Heinkel and Astronautics

The March, 1950, *Bulletin* of the Gesellschaft für Weltraumforschung e.v. (Stuttgart) contains a speech made by Professor Heinkel, the famous aircraft designer, on handing over the "Ehrenbuch der Astronautik" (Roll of Honour of Astronautics), which he has presented to the G.f.W. Professor Heinkel's views are of such interest that we give them in full:—

"The idea of space-travel and its scientific and technical realisation has undoubtedly grown out of the pioneering work of a few scholars and technicians to become a goal for all mankind. Thus the rocket, after many years of misuse, will lead men out into the world of stars and by this achievement will bring about an era of peaceful co-operation between nations. The workers towards this advance into space are an example of the fruitful collaboration between men and women of science from all races. The names and achievements inscribed in the Roll of Honour will be an inspiration and a challenge to young workers in astronautics."

Professor Dr. Heinkel presents the *Ehrenbuch der Astronautik* to Professor Dr. Schaub on behalf of the Gesellschaft für Weltraumforschung. *Left to right:* Prof. Dr. Heinkel, Dipl. Ing. H. Gartmann, H. H. Kœlle, Prof. Dr. Schaub, Mr. Doane and Prof. Dr. Pirath.

Weltraumfahrt

We are particularly pleased to receive the latest issue of *Weltraumfahrt*, the official organ of the *Gesellschaft für Weltraumforschung* (Stuttgart), which is now an excellently-printed 24-page journal containing much interesting material. The January, 1950, issue has three main articles. Dr. Eugen Sänger discusses the constructional problems of rockets using gaseous reaction (*i.e.* the normal type of motor, as opposed to possible future types using ion beams, radiation

pressure, etc.). He gives an interesting table of ideal exhaust velocities for 14 propellants and five oxidisers (H_2O_2, HNO_3, O_2, O_3, F_2) and from the resultant 70 values it appears that the beryllium-ozone and beryllium-oxygen reactions would give ideal exhaust velocities of over 7 km./sec.! A table of combustion-chamber materials is also given: the highest melting-point quoted (a tantalum-carbide, hafnium-carbide alloy) is almost 4,000° C.

The second paper (by H. Kühme) derives air-resistance curves for a vertically ascending rocket, while Dr. G. Loeser discusses the protective effects of the atmosphere.

An account of the inauguration of the Herman Oberth medal gives a picture and short biography of Professor Oberth. The journal ends with news items and short book reviews, from which it appears that science-fiction is as popular in German astronautical circles as here. We are also amused to see a little cartoon showing the Moon carrying a notice which must be all too familiar in Western Germany—OFF LIMITS!

Lecture Notes

Some notes useful for lecturers to outside bodies have been prepared and are available to members of the Society on request. As announced in the 1949 *Annual Report*, the Council would welcome volunteers to give such lectures. They are requested to enclose details of their qualifications, the areas in which they could lecture, and the kind of organisation to which they would be prepared to talk, when applying for copies of these notes.

Book List No. 3

A new edition of the Society's Book List, brought up to date, is now available to all members on application to the Secretary.

"Destination Moon"

A new film on spaceflight is being produced by George Pal at General Service Studio. The director of photography is Lionel Lindon, A.S.C., and Chesley Bonestell assisted in the set design. Script is by Robert Heinlein and art direction by Ernest Fegte. The photography is in Technicolor and the film, "Destination Moon," is scheduled to be released in the United States in August.

Quite a large team of technical advisers was assembled so that the film would be authentic and scientifically accurate and huge interior sets depicting the surface of the Moon and the background of black sky with the stars and Milky Way and the Earth were constructed. The spaceship and camera were capable of being rotated so that the actors could walk up the walls and across the ceiling by means of their "magnetic" shoes. This facility was also needed for shots of the actors leaving the ship in space to make repairs.

From reports it appears that this film will be extremely interesting and realistic and it is to be hoped that it will be included in those imported into this country for screening.

"Supersonic" Still not Fast Enough to Describe Future Speeds

Aeronautical engineers from throughout the U.S.A. at the eighteenth general meeting of the Institute of the Aeronautical Sciences, held in January, in New York, recognised formally that top-flight speeds of the future no longer can be indicated adequately by the term supersonic. Lectures concerned hypersonic speeds, possible only at altitudes measured in scores of miles, where air is so thin that the flow condition can only be duplicated in wind tunnels from which all air has been pumped out and some new gas introduced which more nearly imitates outer space conditions.

A scientist from government laboratories in Virginia described a laboratory method of simulating hypersonic airflow conditions. Mr. G. Grimminger, who is now a Scientific Warfare Advisor in the Department of Defence (but will be remembered by B.I.S. readers for his work on the meteor danger and the upper atmosphere), reported on characteristics of hypersonic flow around objects, with collaboration in the lecture from G. B. W. Young, of Rand Corporation, a California research agency.

Other lectures, from United Aircraft and M.I.T., discussed temperature distributions at supersonic speeds, and the qualities of certain wing shapes at these speeds.

Astrophysics from an Artificial Satellite

The publicity given in the public press to Defence Secretary Forrestal's statement in December, 1948, will have left few members unaware of the official interest of the United States in the possibility of the construction of an artificial satellite. Active study of the problems involved and the uses of such an "Earth Satellite Vehicle" began as early as **1946**, as is shown by a number of reports now published by the Rand Corporation. (One such report, by Grimminger, on the danger from meteors, has been summarised in a recent *Journal*, **8**, 157, June, 1949.) Military advantages were not the only ones considered, for a copy of a report by the eminent astronomer, Dr. Lyman Spitzer* of Yale, entitled *Astronomical Advantages of an Extra-Terrestrial Observatory* and dated September 1, **1946**, has just come to hand. In it, a brief discussion is given of astronomical problems, to the solution of which observations from an artificial satellite could contribute by overcoming the observational limitations set by the Earth's atmosphere. (A discussion of these limitations is not given explicitly, but an account has been given by Ovenden in the paper *Astronomy and Astronautics* (J.B.I.S., **8**, 180, September, **1949**), which paper might well be read in conjunction with that of Dr. Spitzer.

The author considers three types of available instruments. With a small ultra-violet spectrograph, continuous recording of the solar radiation would be possible. It is the Sun's short wavelength radiation which determines the state of the terrestrial ionosphere and quality of radio signals, and is thus of military as well as astronomical importance. Observations of the solar radiation passing through different heights of the Earth's atmosphere would enable the

* *An article by Dr. Spitzer appears on page* 131 *of this Journal.*

state and distribution of the different terrestrial atmospheric elements to be determined.

With a little greater ambition, the author next considers a 10-in. telescope with a photoelectrically-recording spectrograph, which would yield valuable data on the ultra-violet radiation of solar features (sunspots, prominences, flares, etc.), thus overcoming one of the greatest obstacles to the present solution of solar physical problems. If stellar spectra were obtainable, the resonance lines of common stellar elements, which mostly lie in the ultra-violet, would be available for study, and also accurate bolometric magnitudes and colour temperatures of hot stars whose spectral maxima lie in the ultra-violet, would be accurately determined for the first time. The observation in the ultra-violet of highly ionised atoms would enable physical conditions in stellar atmospheres to be better appraised. Other problems considered, which have been mentioned in the previous reference, are the structure of interstellar matter and the analysis of more eclipsing binaries.

Nothing daunted, Dr. Spitzer then visualises the mounting of a large telescope of 200–600 in. aperture, the suggested problems for such an instrument being concerned with galactic and metagalactic structure and (homing suddenly from the remotest depths of the Universe) the nature of the surface markings of the planets.

Dr. Spitzer's very brief survey makes no pretence to be complete, and many problems to which a satellite vehicle could contribute are not considered, but the whole suffices to emphasise once again the importance of astronautical research to astrophysics. The realisation of the project lies in the future, if not the far future, and it is certain that many of the problems considered will have either ceased to be problems, or have assumed only modest importance, being usurped by others as yet unrecognised, by the time plans come to fruition; for example, the nature of the markings on Mars may well be solved at the next apparition in two years' time by ciné-photography with the Earth-bound 200-in. telescope. But, to repeat a previous remark "The particular problems may go, but the properties of the atmosphere will always be with us"—until, in Dr. Spitzer's words, the Earth satellite vehicle can "revolutionise astronomical techniques and open up completely new vistas of astronomical research."

500,000,000 Gravities!

Recent work by J. W. Beams (*Review of Scientific Instruments*, **21**, 182–4, February, 1950) on centrifuges with magnetic suspension reveals that speeds of 800,000 revolutions per *second* have been attained with very small steel rotors (diameters around a hundredth of an inch). It has thus been possible to achieve "a centrifugal field in excess of one-half billion gravities."

One may well wonder if true gravitational fields of this magnitude exist naturally anywhere in the universe, even on the "neutron stars," whose existence has been postulated on theoretical grounds by Professor Zwicky. If a star with such a surface gravity did exist, it could not be much larger than the Earth, for otherwise not only would its escape velocity be greater than light (so that it would be invisible), but it would, according to the theory of relativity, fold space completely around it and so retire into a private universe.

From the World's Press

In his recent series of five extremely interesting radio talks on "The Nature of the Universe," Dr. Fred Hoyle again expressed his belief in the fact that the Universe contains untold numbers of planets, many of which, on a simple statistical basis of probability, are likely to harbour intelligent life-forms.

* * * *

During February, the London *Daily Express* printed a series of extracts from the Ley-Bonestell book *Conquest of Space*, which should have done much to arouse popular interest in the subject.

* * * *

At a recent function held at the plant of Reaction Motors, Inc., Mr. Lovell Lawrence (President of the firm) told the American Press that he believed the next 10 years would bring the development of rocket-propelled air liners capable of crossing the U.S.A. in 90 minutes. This essay in aeronautical prophecy had already been outdone, however, by Dr. Hsue Shen-Tsien (Goddard Professor of Jet Propulsion at Caltech). He recently described to the A.R.S. what he thought a future trans-Continental rocket-liner, capable of making the trip in "less than an hour," would look like. It would weigh 50 tons at take-off (of which 37 tons would be fuel) and be 80 ft. long, with a maximum speed of 9,000 m.p.h.

* * * *

On January 16, astronomer Tsuneo Saeki, of the Osaka Observatory, in Japan, claims to have seen a vast grey cloud appear on the face of Mars. Within 30 minutes, it grew to 900 miles diameter and rose to an estimated height of 60 miles.

Some newspapers recalled the explosions observed on Mars in H. G. Wells's *War of the Worlds*, as a prelude to the invasion of Earth. Others speculated that perhaps the Martians had anticipated both the U.S.A. *and* the U.S.S.R. in the production of the hydrogen bomb, but *Time* says that Dr. Kuiper (the American astronomer) described such talk as "irresponsible."

No further phenomena have been reported, but the interest shown in the story (like the flying saucers) would appear to confirm the wide popularity now claimed for the type of literature known as "science-fiction." One day, some news-story of this general character may turn out to be true—and won't the journalists be surprised then!

* * * *

Following the earlier outbreak occasioned by an article in the U.S. magazine *True* (YES, you heard us aright), mid-March brought another crop of flying-saucer reports. They were seen over various parts of God's Own Country, but, as the London *Star* commented in verse, they apparently considered that the rest of the world was not their cup of tea. The *News-Chronicle* Washington correspondent said he had seen only one explanation advanced why extra-terrestrial visitors should be showing such an intensive interest in Earth just now. This was in "a fascinating short story" (science-fiction again!) which

suggested that they had observed atomic explosions here, and had come to see whether we needed to be placed in quarantine for the safety of the rest of the Solar System. (This would seem to offer the only decisive solution to the international situation possible under present circumstances.)

Best of all reports re-printed over here was a *Daily Telegraph* stop-press story that a 23-in. man had been found in a force-landed saucer with a 40-ft. diameter motor (type unspecified). Alas, the next day's paper did not follow up this promising start.

Our Chairman and Secretary wish us to say that they are tired of answering questions beginning "What is the explanation of this flying-saucer business . . . ?" If any saucer-crews care to present themselves at the Society's Headquarters with satisfactory credentials and a $40 answer to this enquiry, they will be made very welcome. Martian and Venusian papers please copy.

(Arthur Clarke wonders a little guiltily if the story mentioned by the *News Chronicle* was his "Loophole" (*Astounding Science Fiction*, April, 1946; reprinted *Treasury of Science Fiction*) which had precisely the plot outlined.)

"Is the Minister of Supply aware that Britain is now the only country without flying saucers?"

Reproduced by courtesy of the Editor of "The Star"

* * * *

Two men in Brazil are stated to have been sent to jail for trying to sell flying saucers on a "10 dollars down" future delivery basis.

* * * *

On the day of the General Election (February 23), the *Daily Telegraph* printed an item headlined "Oxford Looks Beyond the Poll," which covered Arthur Clarke's lecture to "The Heretics" (an undergraduate society) the night before. Also in the same issue was an editorial entitled "Away from It All," which is reproduced below:—

AWAY FROM IT ALL

It is not, we hope, an omen of the outcome of to-day's election that an Oxford undergraduate society should have spent the eve of it considering means of escaping not merely from Britain, but from the globe itself. Their visionary lecturer, indeed, offered small prospect of being able to emigrate to another planet within the next half-century. Knowing that he still has time to change his mind, the cautious youth will play for safety and put his name on the emigrant list now.

Earth patriots, however, will cling to the hope that terrestrial amenities may yet improve sufficiently to induce escapists to prefer the home-planet after all. Even as the first spaceship prepares to slip its moorings for Mars, its voyage may be restrained by news which would make Earth tenable once more. Income-tax reduced to 7s. 6d., the dollar gap bridged a "Yes" from the Russians—such events surely would bring the migrants tumbling from their cabin, resolved to stick it out on their native planet, at least until the next meetings of the United Nations and the O.E.E.C.

ABSTRACTS

Edited by J. HUMPHRIES

With this issue we commence using a new layout of the Abstracts. This is being done in order to conform with standard methods of abstracting in general use. The following is a list of abbreviations of journal titles which will be used in abstracts. Additions to this list will be published from time to time in later issues of the *Journal*.

Aero. Dig.	Aero Digest.
Aero. Engng. Rev.	Aeronautical Engineering Review.
Aircraft Engng.	Aircraft Engineering.
Air Trails Pict.	Air Trails Pictorial.
Amer. Gas Ass. Mon.	American Gas Association Monthly.
Amer. J. Phys.	American Journal of Physics.
Antiaircr. J.	Antiaircraft Journal.
Astrophys. J.	Astrophysical Journal.
Aust. J. Sci. Res.	Australian Journal of Scientific Research.
Aviation Wk.	Aviation Week.
B.O.P.	Boys' Own Paper.
Bull. Amer. Met. Soc.	Bulletin of the American Meteorological Society.
Business Wk.	Business Week.
Canad. J. Res.	Canadian Journal of Research.
Chem. Abstr.	Chemical Abstracts.
Chem. Engng. News.	Chemical & Engineering News.
Coast Artill. J.	Coast Artillery Journal.
Comment. Phys. Math., HelsingF.	Commentationes Physico-Mathematicae.
C.R. Acad. Sci., Paris.	Comptes Rendus Hebdomadaires des Séances de l'Academie des Sciences.
Engng. J., Montreal.	The Engineering Journal.
Engrs. Dig.	Engineers' Digest.
Everybody's Wkly.	Everybody's Weekly.
Fuel Abstr.	Fuel Abstracts
Industr. Engng. Chem.	Industrial & Engineering Chemistry.
J. Aero. Sci.	Journal of the Aeronautical Sciences.
J. Amer. Rocket Soc.	Journal of the American Rocket Society.
J. Appl. Mech.	Journal of Applied Mechanics.
J. Appl. Phys.	Journal of Applied Physics.
J. Res. Nat. Bur. Stand., Wash.	Journal of Research of the National Bureau of Standards.
J. Soc. Mot. Pict. Engrs.	Journal of the Society of Motion Picture Engineers.
J. Tech. Phys., U.S.S.R.	Journal of Technical Physics.
J. Soc. Automot. Engrs.	Society of Automotive Engineers' Journal.
Mém. Artill. Franc.	Mémorial de l'Artillerie Française.
N. Amer. Skyline.	North American Skyline.
Pacif. Rockets.	Pacific Rockets.
Phys. Rev.	Physical Review.
Proc. Inst. Radio Engrs., Aust.	Proceedings of the Institution of Radio Engineers, Australia.
Publ. Sci. Min. Air France.	Publications Scientifiques et Techniques du Ministère de l'Air.
Quart. Trans. Soc. Automot. Engrs.	Society of Automotive Engineers' Quarterly Transactions.

Rech. Aerodyn.	Recherche Aérodynamique.
Rev. Sci., Paris.	Revue Scientifique.
Sci. Abstr.	Science Abstracts.
Sci. Amer.	Scientific American.
Techn. Rev.	Technology Review.
Trans. Amer. Soc. Mech. Engrs.	Transactions of the American Society of Mechanical Engineers.
U.S. Air Serv.	U.S. Air Services.
U.S. Cen. Air Docum. Off. (N.-A.F.) Tech. Data Dig.	U.S. Central Air Documents Office (Navy-Air Force) Technical Data Digest.
U.S. Dep. Comm., Off. Tech. Serv.	U.S. Department of Commerce, Office of Technical Services
Voordr. K. Inst. Ing.	Voordrachten gehouden voor het Koninklijk Instituut van Ingenieurs.
West. Flg.	Western Flying.
World Petrol.	World Petroleum.
Z. Ver. dtsch. Ing. [*V.D.I.*]	Zeitschrift des Vereines deutscher Ingenieure.

As an example, the first abstract below refers to the March, 1949, issue of the *Australian Journal of Scientific Research*, Volume 2, pages 63–77.

Many of the Abstracts noted are available on loan to members resident in the British Isles. Requests should be addressed to J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks.

Microwave thermal radiation from the Moon. J. H. PIDDINGTON and H. C. MINNETT. *Aust. J. Sci. Res.*, **2**, 63-77 (March, 1949).

Measurements have been made of the thermal radiation from the Moon in a 15 mc/s band, centred at 24,000 mc/s. The radiation from the whole lunar disc has been measured during several phase cycles. Temperatures corresponding to this radiation have been deduced and curves of temperature against phase angle drawn. One of these corresponds to average temperature over the disc and the other to the temperature of a point on the lunar equator. They are found to be approximately sinusoidal, with amplitudes $\pm$ 40·3° K and 52·0° K respectively and with a phase lag behind the lunar phase angle of about 45° in each case.

These results conflict with previous measurements of temperature at long infra-red wavelengths in both amplitude and phase angle of the temperature curve. An explanation is given in terms of radiation from subsurface layers of the Moon's crust, which are partially transparent to electromagnetic waves at this frequency. The theory is developed quantitatively and it is found that the results are consistent with the existence of a thin layer of dust covering a solid lunar surface. Estimates are made of the temperature of the disc of the new Moon (156° K) and of the deep interior (241° K).

Determination of the elements of meteor paths from radar observation. D. W. R. MCKINLEY and P. M. MILLMAN. *Canad. J. Res.*, A, **27**, 53-67 (*May*, 1949).

Methods of determining meteor velocities from single-station observations are discussed. Where three-station observations are available both the velocity and the elements of the meteor's path through the atmosphere can be computed in favourable cases. These methods are applied to a selected daytime meteor, recorded by three radar stations.

Compilation of thermal properties of hydrogen in its various isotopic and ortho-para modifications. H. W. WOOLLEY, R. B. SCOTT and F. G. BRICKWEDDE. U.S. Dep. Comm., Nat. Bur. Stand., Wash., Res. Pap. R.P. 1932, $0·40. *J. Res. Nat. Bur. Stand.*, Wash., **41**, 379-475 (*November*, 1948).

The available thermal data for H_2, HD and D_2 in solid, liquid, and gaseous states have been brought together, including the distinctive properties of ortho and para forms of H_2 and D_2. Some data not previously published have been added. The thermal data

include thermodynamic functions for the ideal gas state, equilibrium constants, data of state, viscosity, and thermal conductivity with dependence on the pressure, vapour pressure, solid-liquid equilibria, specific heats and latent heats. Values of state derivatives useful in thermodynamic calculations have been given for normal hydrogen, and the related differences between thermodynamic functions for real and ideal gas states have been evaluated. A temperature-entropy diagram for normal H_2 in the range of experimental data is also given. The compiled thermal properties of hydrogen are presented in 38 tables, 33 graphs and numerous equations. The sources of the data have been given in an extensive bibliography.

Molecular aerodynamics. M. LUNTZ, *Rech. Aérodyn.*, 17-33 (*Jan.-Feb.*, 1949). In French.

Sudden changes of compression produced at non-equilibrium chemical transformations in a supersonic gas stream. I. I. NOVIKOV, *J. Tech. Phys.*, U.S.S.R., **19**, 1053-5 (*September*, 1949.) In Russian.

Optical instrumentation for guided missiles. D. REUYL. *Sky and Telescope*, 299-301 (*October*, 1949).

Brief descriptions of, and results obtained with, conventional movie cameras, tracking cine-theodolites, stationary plate-cameras, and telescopes. Stationary plate-cameras have been developed, giving a probable error of the space co-ordinates of the order of a foot at an altitude of 20 miles.

Rocket applications of electrostatic generating voltmeters. J. F. CLARK, Jr. *Instruments*, **22**, 1007-9 (*November*, 1949).

By a suitable distribution of several electrostatic generating voltmeters over the skin of a rocket, it is possible to separate the field due to a charge on the rocket from that due to potential gradients already existing in regions above the Earth's surface. This is useful for corona investigations. The principles and characteristics of the equipment used at White Sands are discussed. Results obtained during rocket firings are not reported.

Instrumentation of V.2 rockets to obtain data on the physics of the upper air. M. O'DAY. *Proc. 11th Internat. Cong. App. Mech.*, **2**, Pt. II, 515-24 (1948).

Gives requirements for upper-air research rockets and describes layout of modified V.2, difficulties encountered and results so far obtained. These are:—

(1) Ambient temperature and pressure. Some data up to 60 miles using ionisation pressure gauges, but analysis of records very difficult. Work in progress to obtain ambient temperature directly from Mach number.
(2) Parachute studies. Studies so far indicate that it should be possible to recover portions of rockets by parachute, but that the techniques are very difficult.
(3) Sky brightness. Measurements being made for selected wave-lengths at various heights.
(4) Electron density of ionosphere. Only one set of data so far obtained.
(5) Oblique incidence. Tests to show that various layers of the ionosphere together with the surface of the Earth form a type of spherical wave-guide, have been successful.
(6) Soft X-ray measurements. To check theory that in the corona of the Sun there exists temperatures of the order of $10^{6\circ}$ K, no success so far.
(7) Luxembourg effect. Experimental study of the use of high energy-density electromagnetic radiation at the gyro-frequency to intensify the light of the night sky. Primary purpose is to obtain information on the chemical composition of the atmosphere. One test only—no results.
(8) Photography. Some colour films taken of the Earth.

Cloud observations from rockets. D. L. CROWSON. *Bull. Amer. Met. Soc.*, **30**, 17-22 (*January*, 1949).

Photographs of cloud formations over 500,000 square miles of S.W. U.S.A. from a V.2 rocket at heights of up to 100 miles are analysed and compared with weather maps for the region. The potentialities of rocket photographs or television for meteorology are pointed out. (From *Sci. Abstr.*, *A*, **52**, 352, abstr. 2831.) (*June*, 1949.)

The earth viewed from high altitudes by rockets. M. DÉRIBÉRÉ. *Nature*, Paris, 115-7 (*April*, 1949). In French.

Dynamic probe measurements in the ionosphere. A. REIFMAN and W. G. DOW. *Phys. Rev.*, **76**, 987-8 (*October* 1, 1949).

The atmosphere and its characteristics. H. E. ROBERTS. *Aero. Engng. Rev.*, 18-31 (*October*, 1949). Extended rev., "The Atmosphere and Its Characteristics," *Aeroplane*, **77**, 672-3 (*November* 18, 1949).

This paper is dedicated to presenting a broad non-mathematical résumé of the present state of knowledge of the Earth's atmosphere. The relationship of the Earth's atmospheric characteristics to the fields of aeronautics and astronautics is discussed. It is shown that the rarefied regions of the upper atmosphere require the extension of aerodynamic theories into new realms of fluid mechanics. These realms are defined in terms of the fundamental aerodynamic parameters—Reynolds Number and Mach Number. The problems of flight through and beyond the Earth's atmosphere are reviewed with respect to the influence of atmospheric characteristics upon them.

A discussion of many of the more important physical characteristics of the atmosphere up to altitudes of 1,000 miles is presented. The relations of these characteristics to the human body, meteorology, and communications, are briefly reviewed.

How much force can body withstand? C. F. LOMBARD. *Aviation Wk.*, **50**, 20-1, 23-5, 27-8 (*January* 17, 1949). Reviews present state of knowledge of limits of endurance of human body to acceleration forces applied in various directions.

Multi-channel radio telemetering for rockets. G. H. MELTON. *Electronics*, **21**, 106-9 (*December*, 1948). The Aerobee system for transmitting cosmic-ray and other high-altitude data is described.

Transistor oscillator for telemetering. W. LEHAN. *Electronics*, **22**, 90-1 (*August*, 1949).

Audio oscillator built around crystal triode, used to frequency modulate rocket telemetering system, is described. Transistor characteristics are reviewed and advantages over vacuum-tube equivalent are enumerated. Design data for similar circuits in other applications are presented.

The design and development of rocket engine power-plants for aircraft. A. K. HUSE. *Soc. Automot. Engrs. Prepr.*, 11 pp. (*April*, 1948).

Rockets and ram jets. E. ELTHAM. *World Petrol.*, **19**, 58 (*October*, 1948) (Abstr. in *Fuel Abstr.*, **5**, abs. 1386).

Radiation from rocket flames and its effect on rocket performance. S. S. PENNER. *Amer. J. Phys.*, **6**, 475-83 (*December*, 1948).

The present review is primarily concerned with (*a*) a discussion of the experimental evidence relating to the nature of the radiation from rocket flames, and (*b*) a survey of the theoretical and experimental results relating to the manner in which radiant energy is absorbed by solid propellant grains whose rate of burning and behaviour are changed because of the absorption of radiant energy (26 refs.).

Atomic power and aircraft propulsion. A. KALITINSKY. *Quart. Trans. Soc. Automot. Engrs.*, **3**, 1-17, 40 (*January*, 1949).

Ramjets, pulsejets and rockets. *Aero Dig.*, **58**, 91-2 (*March*, 1949). Includes brief notes on Aerojet 14A, S-100, D5, JATO unit and reaction motors 6000 C-4.

The 109-718 auxiliary rocket power unit. H. GARTMANN. *Inter Avia*, **4**, 413-5 (*July*, 1949).

This motor, intended as an auxiliary unit for use with the Jumo 004 and B.M.W. 003 turbo-jets, was developed by B.M.W. from the 109-510 unit. The combustion chamber of the production model had an inner shell of light alloy, impinging jet injectors and fuel film-cooling. Propellant pumps were driven through a gear-train from the turbine. Propellants were 98-99 per cent. nitric acid and Tonka 250 (50 per cent. crude xylidine F and 50 per cent. triethylamine, by volume). Thrust was 1,200 kgs. and total weight 46·77 kgs. Full details of the unit, its components and development are given.

Rockets aim at mass output. *Business Wk.*, 31-2 (*August* 13, 1949).

X.4—Germany's smallest liquid rocket. H. GARTMANN. *Inter Avia*, **4**, 553-5 (*September*, 1949).

The nitric acid/Tonka 250 (50 per cent. triethylamine, 50 per cent. xylidine by vol.) rocket-motor designated 109-548 was designed by B.M.W.'s in 1942-3 for use in the X.4 guided missile. Maximum thrust was about 140 kg. with a total impulse of 1,400 kg. secs.

on the first serial models. Concentric, spirally-wound propellant tanks were used and pressurised by means of compressed air. The thrust was arranged to decrease during the 16-sec. run. Measurements of thrust and motion and the development of the projectile are discussed.

Near-equilibrium criteria for complex chemical reactions during flow through a nozzle. S. S. PENNER. *J. Chem. Phys.*, **17**, 841-2 (*September*, 1949).

N.A.A. builds huge propulsion lab. *Aviation Wk.*, **51**, 28-9 (*December* 19, 1949).

On the trajectories of rockets leaving a base at altitude. R. BOUTET. *Rev. Sci.*, Paris, 675-6 (*November*, 1949). In French.

Early Chinese rockets. T. L. DAVIS. *Tech. Rev.*, **51**, 101-2 (*December*, 1948).

Aerobee sounding rocket; a new vehicle for research in the upper atmosphere. J. A. VAN ALLEN *et al.*, *Science*, **108**, 746-7 (*December* 31, 1948).

On the development of a liquid-propellant rocket. G. ZEUNERT. *Z. Ver. dtsch. Ing.* (V.D.I.), **91**, 57-64 (*February* 1, 1949). In German.

"The rocket's red glare." *Aero. Dig.*, **58**, 42-3 (*April*, 1949). Photos of take-offs of U.S. rockets.

Space weapons on the way. *Inter Avia*, **4**, 366-7 (*June*, 1949). The Aerobee rocket.

The guidance of rocket missiles. H. OBERTH. *Inter Avia*, **4**, 477-80 (*August*, 1949).
Describes various beam guidance and command control systems. Examples discussed are Wasserfall, Hs 117 and Oberth's own design of A.A. rocket, the HB-L.59.

Guided-missile development. C. B. MILLIKAN. *Aero. Dig.*, **59**, 38-9, 102 (*September*, 1949). A general review of the work of the Committee on Guided Missiles.

The Viking's flight. *Life*, **27**, 52-3 (*October* 3, 1949). Colour illus. of Viking take-off.

Australia's long-range weapons range. S. A. MORRISON. *Antiaircraft J.* (*November-December*, 1949), **92**, 40-1.

By the rocket's red glare: Inyokern. W. R. HUGHES. *Antiaircraft J.*, **92**, 42-3 (*November-December*, 1949). Activities of the Naval Ordnance Test Station, Inyokern, Calif.

The rocket problem. L. A. SKINNER. *Ordnance*, **34**, 184-5 (*November-December*, 1949).
Artillery rockets suffer from the defect of high dispersion. With solid propellants this is due chiefly to the difficulty of keeping the thrust axis on the geometric longitudinal axis of the projectile with sufficient accuracy. This is not due to fabrication difficulties, but to gas-flow deviation. Two solutions are suggested: (1) the use of fast-burning propellants so that the propellant is all burnt before the projectile leaves the launching rack, and (2) the use of liquid-propellant rocket motors.

Step-rockets. J. SCHMIDTMAYER. *Letectvi*, **25** (1949), 542-5 (*November* 14); 564-6 (*November* 28); 594-5 (*December* 12). In Czech. Mathematical treatment with examples.

U.S. high-speed research airplanes. *Aviation Wk.*, **50**, 40,.43-4, 47 (*February* 28, 1949).

U.S.A.F. reveals three new supersonic planes. R. MCLARREN. *Aviation Wk.*, **50**, 12-14 (*March* 7, 1949), Convair 7002, Republic XF-91, Lockheed XF-90.

Jet-plus-rocket. *Aero. Dig.*, **58**, 58 (*April*, 1949). Data on various aircraft with combinations of jet and rocket motors.

Jato Junior. *Inter Avia*, **4**, 436 (*July*, 1949). Assisted take-off of Navion.

Factors affecting the range of rocket-powered aircraft. T. F. REINHARDT. *Aero. Engng. Rev.*, **8**, 32-5 (*October*, 1949).
This paper gives a method of calculating the performance figures for a rocket-propelled aircraft. It is shown that the propellant density impulse has a much greater influence than the specific impulse. Sample calculations for an aircraft capable of flying for five mins. at

800 m.p.h. and 40,000 ft. altitude, are given. It is concluded that the rocket-powered aircraft will be characterised by small size, but large weight and high wing loading. It will be capable of exceptionally fast take-off, climb, and flight speed, but of relatively short range.

Douglas Skyrocket hits supersonic speed. R. McLarren. *Aviation Wk.*, **51**, 10-11 (*October* 3, 1949).

How JATO cuts Navion take-off. *Aviation Wk.*, **51**, 40 (*November* 7, 1949).

Pyrotechnics. Now and later. *Aeroplane*, **77**, 631 (*November* 11, 1949).

Tonic sonics. S. H. Evans. *Flight*, **57**, 16-20 (*January* 5, 1950).
A description of the Douglas D-558-2, the Skyrocket. This supersonic research aircraft is powered by a Westinghouse J-35 turbo-jet rated at 4,000 lb. static thrust for take-off and normal flight and a Reaction Motors 6,000-lb. liquid oxygen/alcohol rocket-motor for supersonic flight. Two 1,000-lb. jettisonable JATO units may also be used. 250 U.S. gallons of gasoline for the turbo-jet and 3,000 lb. of rocket propellants are carried. Rocket duration is 1½ mins. full thrust, or about 4 mins. quarter-thrust. Fully-loaded weight is around 16,000 lb. and take-off wing loading is 120 lb./sq. ft. Structural and aerodynamic descriptions are given in some detail.

Space routes. V. Gradecak. *Weltluftfahrt*, **1**, 26-7 (*January-February*, 1949). In German. A discussion of the calculation of the flight-path of a space-ship within the solar system.

Star waggon: U.S. military men plan earth satellite vehicle. *Business Wk.*, p. 39 (*January* 8, 1949).

On the subject of shooting to the Moon. J. Chazy. *C.R. Acad. Sci.*, Paris, **228**, 447-50 (*February* 7, 1949). In French.

Exploring space. K. W. Gatland. *Everybody's Wkly.*, 14-16 (*June* 18, 1949).

The laws of motion in space travel. E. Sänger. *Inter Avia*, **4**, 416-8 (*July*, 1949). An analysis of the possible trajectories of space-rockets. Estimates of the altitude losses for artificial satellites are made.

Journey into space. H. E. Ross, *B.O.P.*, **72**, 38-9, 71 (*November*, 1949).

Missiles for outer space. J. P. Field. *Antiaircraft J.*, **92**, 15-19 (*November-December*, 1949). A general review of the propulsion problems.

Study of the decomposition of hydrogen peroxide by calcium permanganate and study of the manufacture of concentrated hydrogen peroxide. L. S. Mathieu. *Note Tech. No.* 27, *Publ. Sci. Min. Air France*, 13 pp. (1948). In French.
Theoretical and practical studies of the decomposition of hydrogen peroxide by calcium permanganate and study of the methods of production of hydrogen peroxide of up to 94 per cent. concentration.

Evaluate nitromethane for rockets. *Aviation Wk.*, **50**, 27-8, 30, 33, 37 (*May* 16, 1949).

Elevated-temperature properties of several titanium carbide base ceramals. G. C. Deutsch, A. J. Repko and W. G. Lidman. *N.A.C.A. Tech. Note* 1915, 47 pp. (July, 1949).
An investigation was made to determine the properties of ceramals of titanium carbide plus refractory metals and to study the fundamental nature of ceramals. The properties evaluated were elevated-temperature tensile strength, elevated-temperature modulus of rupture, coefficient of linear expansion, and density. A study was also made of the microstructure of the ceramals and of the coatings formed during exposure to oxidising conditions.

Meeting combustion problems. J. J. Turin and J. Huebler. *Amer. Gas Ass. Mon.*, **31**, 15-17, 51-3 (*July-August*, 1949) (*Abstr.* in *Fuel Abstr.*, **6**, Abs. 5210) (*December*, 1949).

Ignition composition. E. J. Hanley, *U.S. Pat. No.* 2,476,370 (*July* 19, 1949) (*Abstr.* in *Chem. Abstr.*, **43**, Col. 86836) (*November* 10, 1949).

Tetranitromethane. K. F. HAGER. *Industr. Engng. Chem.*, **41**, 2168-72 (*October*, 1949). A method of promising technical applicability for manufacture of tetranitromethane is presented in detail. It was based on work done by Orton and McKie and improved in a continuous glass laboratory apparatus. This apparatus was designed for a capacity of 10 kg. per day with a possible increase up to 14 kg. Acetylene is allowed to react with nitric acid, producing nitroform. The mixture of nitroform and nitric acid is converted to tetranitromethane by means of sulphuric acid at elevated temperature. This continuous process yields about 90 per cent. tetranitromethane, based on the nitric acid consumed, when all waste gases have been reclaimed carefully. Properties and explosive powers with various materials are also discussed.

On burning of powder. E. PEKKARINEN. *Comment. Phys. Math.*, Helsingf., **13**, 114 pp. (*October*, 1947). In Swedish. Tests on three propellants fired in open and closed vessels. (*Abstr.* in *Fuel Abstr.*, **6**, abs. No. 4265) (*November*, 1949).

Hermann Oberth, shaper of things to come. *Inter Avia*, **4**, 558-61 (*September*, 1949).

An interview, written in conversational form, with Oberth. His wartime work at Peenemunde and W.A.S.A.G. is described, together with his ideas on a ram-jet aircraft and the possibilities of space-flight.

RECENT AND FORTHCOMING MEETINGS

February 3, 1950 (Friday). "Interplanetary Exploration," by G. V. E. Thompson, to the Sixth Form Society, The County School for Boys, Gayton Road, Harrow, at 4.30 p.m.

February 10, 1950 (Friday). "Interplanetary Travel and Rocket Flight," by G. V. E. Thompson, to the Science Society, South-East Essex Technical College and School of Art, Longbridge Road, Dagenham, Essex, at 4.30 p.m.

March 21, 1950 (Tuesday). "Interplanetary Travel and the Work of the B.I.S.," by G. V. E. Thompson, to the Discussion Group of the International Youth Council in Britain, International Youth Centre, 3, Harrington Road, London, S.W.7, at 8.15 p.m.

April 13, 1950 (Thursday). "Interplanetary Travel and Rocket Flight," by G. V. E. Thompson, to the North Woolwich Branch, Association of Scientific Workers, at the Kent Arms, Albert Road, North Woolwich, E.16, 7 p.m.

April 21, 1950 (Friday). "Interplanetary Travel," consisting of two lectures, *The Dynamics of Space Flight*, by A. C. Clarke, and *Some Problems of Interplanetary Navigation*, by Dr. R. d'E. Atkinson, to the Institute of Navigation, at the Royal Geographical Society, 1, Kensington Gore, S.W.7, at 5 p.m.

May 20, 1950 (Saturday). "The Sun," by J. C. Farrer, F.R.A.S., to the N.W.D.C. of the Society at the Adult Education Institute, 49, Lower Mosley Street, Manchester 2, at 7. p.m.

May 23, 1950 (Tuesday). "Rockets and Interplanetary Flight," by J. Humphries, to Kelvin and Hughes Engineering Society, Barkingside, Essex, at 6.15 p.m.

July 21, 1950 (Friday). Visit to an Astronomical Observatory to observe the Sun and also Mars and the Moon during daylight, 7 p.m. A visit arranged for members of the N.W.D.C. of the Society. Intending visitors should notify the Branch Secretary as soon as possible, as the party is limited.

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REVIEW

Thermodynamic Charts for Combustion Processes

(By H. C. Hotell, G. C. Williams and C. N. Satterfield. John Wiley & Sons, Inc. In two volumes 100 pp. Obtainable from Chapman & Hall, Ltd., Essex Street, W.C.2, price £2 1s. complete).

This title does not give a fair impression of the wide field so adequately covered by the two volumes of this excellently produced American report. While the second volume does contain the promised charts, the first volume contains an exhaustive description of the thermodynamic processes involved in the Otto cycle engine, the gas turbine (with and without tailpipe reheat), the ram-jet and the rocket. In addition, to enable one to use the appropriate chart in the appropriate manner, are given a series of numerical examples of each process, which in themselves are as good as many a textbook.

Most of the charts (of total heat plotted against entropy) concern the burning of a hydrocarbon fuel in air over a wide range of mixture ratios. In view of the choice of oxidant, these charts are thus not especially applicable to the rocket case.

There is, however, a section of the report (under the heading "Generalised Thermodynamic Charts") purely to deal with the rocket application. In this section, the charts given enable one to determine the performance of rockets having effluxes consisting of any combination of carbon-dioxide, water vapour, oxygen, and nitrogen. These charts can be equally well applied to fuel-rich or oxidant-rich combinations, bi-propellant or mono-propellant systems. In addition, means are provided for determining mean molecular weights and specific heat ratios of the gases, and a table is also presented giving the calorific values of the most probable fuels.

The charts given in this section, in contrast to those in the main part of the report, are rather on the small side, and furthermore are only presented for pressures of 300 lb./sq. in. and 14·7 lb./sq. in. A means of interpolation is provided, however, to enable one to deal with intermediate pressures, but this does tend to make the calculation a little tedious. As in the rest of the report, numerical examples are given which plainly show one how to use the charts, tables and interpolation curves.

None of the basic experimental data (*e.g.* variation of specific heat with temperature or dissociation coefficients) from which the charts have been calculated, is given, but full references are given to the sources of data, and the methods employed to compile the charts are very fully described. It is possible, therefore, to do a rough check of the charts oneself, should one feel this necessary, but on the other hand it is not easily possible to extend the charts by further calculation from fundamental data, should this prove a requirement. Fortunately, the range covered by the charts is, in all cases, generous, and should be quite sufficient for all but the most extreme conditions of operation.

W. N. N.

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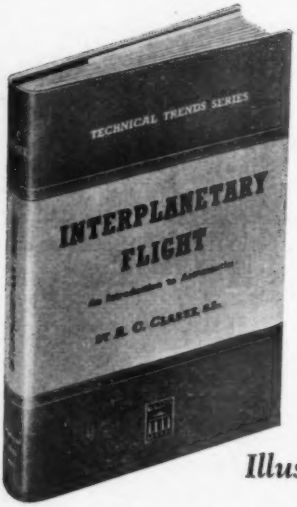

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